# DOCUMENT RESUME

ED 117 317 CE 005 509

| | |
|---|---|
| AUTHOR | Matheny, W. G. |
| TITLE | Training Research Program and Plans: Advanced Simulation in Undergraduate Pilot Training. |
| INSTITUTION | Life Sciences, Inc., Hurst, Tex. |
| SPONS AGENCY | Air Force Human Resources Lab., Williams AFB, Ariz. Flying Training Div. |
| REPORT NO | AFHRL-TR-75-26(II) |
| PUB DATE | Jun 75 |
| NOTE | 103p.; This is the second of two volumes, for the first see CE 005 975; Figure 3, page 83, will not reproduce in microfiche |
| EDRS PRICE | MF-$0.83 HC-$6.01 Plus Postage |
| DESCRIPTORS | Educational Programs; *Flight Training; Operations Research; Planning; Post Secondary Education; Program Effectiveness; *Research Methodology; *Research Projects; Simulation; Simulators; Teaching Methods; *Training Techniques |

ABSTRACT

The study reports the work done by a panel of experts in training research toward defining priority research investigations to be undertaken through the Human Resources Laboratory, Flying Training Division (HRL/FT). A list of recommended investigations judged to be important for increasing the effectiveness of beginning pilot training was formulated based on their suggestions and in conjunction with the capabilities of the HRL/FT facility. Methodological considerations in the planning of long range training research are the difficulties inherent in carrying out classical transfer of training experiments and the configuration of the training simulator. The major elements of an overall plan for a research program in undergraduate pilot training are discussed. These include the six technological base phases and the research phase. The discussion on suggested research is divided into two areas: training methodology and simulator requirements. A list of 23 references is included. Materials used in the different processes of the study are included in a 35-page appendix. (Author/EC)

***********************************************************************
* Documents acquired by ERIC include many informal unpublished *
* materials not available from other sources. ERIC makes every effort *
* to obtain the best copy available. Nevertheless, items of marginal *
* reproducibility are often encountered and this affects the quality *
* of the microfiche and hardcopy reproductions ERIC makes available *
* via the ERIC Document Reproduction Service (EDRS). EDRS is not *
* responsible for the quality of the original document. Reproductions *
* supplied by EDRS are the best that can be made from the original. *
***********************************************************************

AFHRL-TR-75-26(II)

**AIR FORCE**

**HUMAN RESOURCES**

ED117317

# TRAINING RESEARCH PROGRAM AND PLANS:
## ADVANCED SIMULATION IN UNDERGRADUATE PILOT TRAINING

By

W. G. Matheny
Life Sciences, Inc.
227 Loop, 820 Northeast
Hurst, Texas 76053

FLYING TRAINING DIVISION
Williams Air Force Base, Arizona 85224

June 1975
Final Report for Period June 1973 – June 1974

U S DEPARTMENT OF HEALTH,
EDUCATION & WELFARE
NATIONAL INSTITUTE OF
EDUCATION

THIS DOCUMENT HAS BEEN REPRODUCED EXACTLY AS RECEIVED FROM THE PERSON OR ORGANIZATION ORIGINATING IT POINTS OF VIEW OR OPINIONS STATED DO NOT NECESSARILY REPRESENT OFFICIAL NATIONAL INSTITUTE OF EDUCATION POSITION OR POLICY

Approved for public release; distribution unlimited.

**LABORATORY**

CE005509

AIR FORCE SYSTEMS COMMAND
BROOKS AIR FORCE BASE,TEXAS 78235

## NOTICE

When US Government drawings, specifications, or other data are used for any purpose other than a definitely related Government procurement operation, the Government thereby incurs no responsibility nor any obligation whatsoever, and the fact that the Government may have formulated, furnished, or in any way supplied the said drawings, specifications, or other data is not to be regarded by implication or otherwise, as in any manner licensing the holder or any other person or corporation, or conveying any rights or permission to manufacture, use, or sell any patented invention that may in any way be related thereto.

This final report was submitted by Life Sciences, Inc., 227 Loop, 820 Northeast, Hurst, Texas 76053, under contract F41609-73-C-0038, project 1123, with Flying Training Division, Air Force Human Resources Laboratory (AFSC), Williams Air Force Base, Texas 85224. Dr. Thomas H. Gray, Simulation Applications Branch, was the contract monitor.

This report has been reviewed and cleared for open publication and/or public release by the appropriate Office of Information (OI) in accordance with AFR 190-17 and DoDD 5230.9. There is no objection to unlimited distribution of this report to the public at large, or by DDC to the National Technical Information Service (NTIS).

This technical report has been reviewed and is approved.

WILLIAM V. HAGIN, Technical Director
Flying Training Division

Approved for publication.

HAROLD E. FISCHER, Colonel, USAF
Commander

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (*When Data Entered*)

| REPORT DOCUMENTATION PAGE | | READ INSTRUCTIONS BEFORE COMPLETING FORM |
|---|---|---|
| 1. REPORT NUMBER<br>AFHRL-TR-75-26(II) | 2. GOVT ACCESSION NO. | 3. RECIPIENT'S CATALOG NUMBER |
| 4. TITLE (*and Subtitle*)<br>TRAINING RESEACH PROGRAM AND PLANS: ADVANCED SIMULATION IN UNDERGRADUATE PILOT TRAINING | | 5. TYPE OF REPORT & PERIOD COVERED<br>Final<br>June 1973 – June 1974 |
| | | 6. PERFORMING ORG. REPORT NUMBER |
| 7. AUTHOR(*s*)<br>W. G. Matheny | | 8. CONTRACT OR GRANT NUMBER(*s*)<br>F41609-73-C-0038 |
| 9. PERFORMING ORGANIZATION NAME AND ADDRESS<br>Life Sciences Inc.<br>227 Loop, 820 Northeast<br>Hurst, Texas 76053 | | 10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS<br>62703F<br>11230307 |
| 11. CONTROLLING OFFICE NAME AND ADDRESS<br>Hq Air Force Human Resources Laboratory (AFSC)<br>Brooks Air Force Base, Texas 78235 | | 12. REPORT DATE<br>June 1975 |
| | | 13. NUMBER OF PAGES<br>102 |
| 14. MONITORING AGENCY NAME & ADDRESS(*if different from Controlling Office*)<br>Flying Training Division<br>Air Force Human Resources Laboratory<br>Williams Air Force Base, Arizona 85224 | | 15. SECURITY CLASS. (*of this report*)<br>Unclassified |
| | | 15a. DECLASSIFICATION/DOWNGRADING SCHEDULE |

16. DISTRIBUTION STATEMENT (*of this Report*)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (*of the abstract entered in Block 20, if different from Report*)

18. SUPPLEMENTARY NOTES

This report is the second in a series of 2 volumes.

19. KEY WORDS (*Continue on reverse side if necessary and identify by block number*)

pilot training
performance measurement
methodology
simulation

20. ABSTRACT (*Continue on reverse side if necessary and identify by block number*)

In this study, a survey was made among experts in pilot training to determine the important training research problems to be undertaken in order to increase training effectiveness in beginning pilot training. The highest priority problems were examined in the light of the research equipment capabilities of the Air Force Human Resources Laboratory, Flying Training Division and administrative constraints. The initial experiments in the area of training methodology and training simulator requirements are recommended and outlined. The performance equivalence approach to research in these areas is described.

Studies are suggested designed to evaluate the concept and its use in training research.

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (*When Data Entered*)

# PREFACE

This report was completed under Project 1123, USAF Flying Training Development; Task 112303, The Exploitation of Simulation in Flying Training; Work Unit 11230307, Handbook of Research Designs for Advanced Simulation in Undergraduate Pilot Training. Dr. William V. Hagin was project scientist and Dr. Thomas H. Gray was contract monitor.

This report was prepared by Life Sciences, Incorporated (LSI) under USAF Contract F41609-73-C-0038.

## TABLE OF CONTENTS

Page

SECTION 1.0 INTRODUCTION AND BACKGROUND . . . . . . . . . . . 1

2.0 METHOD . . . . . . . . . . . . . . . . . . . . . 2

2.1 Development of a Priority List of Research Questions . . . . . . . . . . . . 2

2.2 Examination of the Capabilities of the Research Facility . . . . . . . . . . . 3

2.3 Delineation of the High Priority Experiments . . . . . . . . . . . . . . . 5

3.0 PRIORITY RATINGS OF RESEARCH PROBLEMS . . . . . 6

4.0 METHODOLOGICAL CONSIDERATIONS . . . . . . . . . . 8

4.1 General Considerations . . . . . . . . . . . 8

4.2 Performance Measurement . . . . . . . . . . 12

5.0 RESEARCH PROGRAM . . . . . . . . . . . . . . . . . 14

5.1 Overall Plan . . . . . . . . . . . . . . . . 14

5.2 Establishing a Technological Base . . . . 16

6.0 RESEARCH OUTLINES . . . . . . . . . . . . . . . 30

6.1 Training Simulator Requirements Research . . . . . . . . . . . . . . . . 30

6.2 Training Methodology Research . . . . . . 52

REFERENCES . . . . . . . . . . . . . . . . . . . . . . 56

APPENDIX A - Letter of Invitation and Instructions to Research Problems Panel . . . . . . . . 59

APPENDIX B - Training Problems List . . . . . . . . . . 61

APPENDIX C - Assignment of Priorities to Training Problems . . . . . . . . . . . . . . . . 69

APPENDIX D - Ranking of Training Problems Based Upon Median Rank (10 Raters) . . . . . . . 71

TABLE OF CONTENTS (CONT'D)

SECTION Page

APPENDIX E - Scenario for Flights of Instrumented T-37 Aircraft . . . . . . . . . . . . . . 74

APPENDIX F - Eye-Movement Recordings and Data Analysis . . . . . . . . . . . . . . . . 77

APPENDIX G - Functional Description of AVIT Device . . . . . . . . . . . . . . . 80

APPENDIX H - A Recommended Design for Experimental Studies Using ASUPT . . . . . . . . . . 89

APPENDIX I - List of Training Problem Panel Members . . . . . . . . . . . . . . . . . 94

## FIGURES

Page

FIGURE 4.1 Performance Measurement Points (MP) in the Man/Machine System . . . . . . . . . . . . . . 13

5.1 Major Elements in a Recommended Undergraduate Training Research Plan Utilizing the HRL/FT Facilities . . . . . . . . . . . . . . . . . 15

5.2 Flight Pattern for Collecting Data in Instrumented T-37 Aircraft . . . . . . . . . . 27

5.3 Order of Trials for Each Block of 2 Sorties for the Flight Conditions Given in Table 5.4 . . . . . . . . . . . . . . . . . . 28

6.1 Initial Four Proposed Visual Display Studies and Necessary Antecedent Investigations . . 35

6.2 Design Format for Visual Display Studies 3 and 4 . . . . . . . . . . . . . . . . . . . . 42

6.3 Paradigm for Test of Performance Equivalence Method for Simulator Motion Requirements . . 47

APPENDIX G

1 Existing AVIT . . . . . . . . . . . . . . . . . 81

2 Simple AVIT Sequence With Confirmation Frames . . . . . . . . . . . . . . . . . . . . 82

4 Simple AVIT Sequence, Confirmation Frames Omitted . . . . . . . . . . . . . . . . . . . . 82

3 Portion of T-37 Instrument Panel Shown on AVIT Screen . . . . . . . . . . . . . . . . . . 83

5 Pre-test or "Wash-Ahead" AVIT Program structure . . . . . . . . . . . . . . . . . . 85

6 "Locked" Seven Question "Wash-Back" Structure . . . . . . . . . . . . . . . . . . . . 85

# TRAINING RESEARCH PROGRAM AND PLANS: ADVANCED SIMULATION IN UNDERGRADUATE PILOT TRAINING (ASUPT)

## 1.0 INTRODUCTION AND BACKGROUND

The Human Resources Laboratory, Flying Training Division (HRL/FT) has developed a unique capability for conducting research on important methods and equipment problems in pilot training. Although the present orientation of the laboratory is toward the solution of undergraduate pilot training problems many of these study results will be generalizable to other training programs. Further, the flexibility of the HRL/FT facility makes it possible to carry out investigations of many problems of training methodology and equipment unique to other pilot training programs.

In planning the HRL/FT facility, contract studies were conducted to specify the training problems to be investigated and the organization and equipment requirements for conducting these investigations. The contract results were reviewed and revised by Air Force personnel and formulated into a basic working document entitled "ASUPT Utilization Concept". Under this concept investigations were centered primarily upon the training problems and training device characteristics necessary for an effective undergraduate pilot training program to be carried out by HRL/FT. Consideration was also given, although not so explicity, to the training problems peculiar to programs beyond undergraduate pilot training.

As indicated, Human Resources Laboratory research management planning focused first upon research designed to increase the effectiveness of the Undergraduate Pilot Training program (UPT). However, management was equally concerned that, to the maximum extent possible, the research be carried out in a way which would make the results generalizable to other levels of pilot training. These considerations led to the decision to initiate a contractor conducted study to identify these general training research questions. These questions were identified through conduct of a survey of those individuals in the training community selected for their experience with the field. This panel of experts was composed of those individuals in government and industry who were recognized as experienced and knowledgeable and who could devote the necessary time to the program. The panel members were asked to identify those research questions which they felt to be pressing in terms of their impact upon pilot training effectiveness. They were asked, also, to order these questions in terms of their importance to increasing the effectiveness of beginning pilot training programs.

The study reported here is the result of work toward the goal of defining those priority research investigations to be undertaken using the research capabilities of HRL/FT. Specifically the study encompassed the following major elements:

1. A statement of the major training research questions.
2. An assignment of priorities by knowledgeable individuals to these research questions in terms of their importance to increasing training effectiveness.
3. Examination of the research questions in light of the research capabilities of HRL/FT.
4. Restructuring the priorities based upon the research capabilities and constraints.
5. Setting forth the details of those experiments and investigations to be undertaken most immediately.

## 2.0 METHOD

The method used in carrying out the work may be described under three major categories of effort. These were (a) development of a priority list of research questions in terms of their impact upon training effectiveness, (b) examination of the capabilities of the research facility and, (c) delineation of the high priority experiments, and investigations to be carried out using the facility.

### 2.1 Development of a Priority List of Research Questions

The development of the list of research questions and the determination of the priorities of the items on the list was carried out in two phases. During the first phase a list of research questions was generated through review of the relevant current literature, and most importantly, by a panel of selected individuals. These individuals were generally recognized as experts in the field of pilot training and research. Their background reflected experience in government agencies, universities and private industry. These panel members were contacted in person or by telephone and a follow-up letter explaining the project in detail, was sent. A copy of this letter is given in Appendix A.

Twelve panel members submitted research questions which they believed to be most relevant to be investigated in order to increase the effectiveness of pilot training. In all, a list of fifty-five research questions was generated. These research questions were not equal with respect to the breadth or scope of effort which would be required. They were, however, those questions which were deemed important enough by this group of experienced individuals to be included in a research program. These questions were defined and explained as concisely and clearly as possible and re-submitted as a total list to each of the individuals on the panel for their judgments as to the priority rankings of the questions. The definitions of the research items are given in Appendix B. The instructions to the raters for assigning priorities are given in Appendix C.

The method suggested to the panel members for assigning priorities was a modified paired comparison technique. This technique required that each item be listed on a 3x5 card. The rater selected one item and then sorted the remaining items as to whether each item was of greater priority or lesser priority than the item selected. This procedure resulted in two groups of items; one of higher priority and another of lower priority than the selected item. Each of these groups were then sorted in a similar manner and the resulting groups further sorted in the same way until groups of four or five items were attained. These items were then ranked as a group and, finally, all items assembled into a priority list. Ten panel members assigned priorities, two being unable to because of other commitments. The results of these listings and the priority ratings are given and discussed in Section 3.0.

## 2.2 Examination of the Capabilities of the Research Facility

The objective of this phase of the contract effort was to examine the AFHRL/FT research capabilities and constraints so that particular research investigations could be detailed and recommended. These recommendations could then be based on these capabilities and constraints, as well as the results from the panel of experts.

The items of research equipment at the AFHRL/FT facility will be identified here only in general terms since they are described in detail in Hagin and Smith (1974).

The major item of research equipment is the Advanced Simulation in Undergraduate Pilot Training (ASUPT) device. ASUPT has come to mean the large scale two cockpit full motion capability simulator with a 7 channel computer generated visual system. This device is described on pages 17 through 26 in Hagin and Smith. To summarize, it has a six degree of freedom motion system and an external world visual system with a field of view which essentially duplicates that of the T-37 aircraft which it represents. The Computer Image Generator (CIG) produces a very extensive variety of objects for making up the visual scene for the pilot.

The ASUPT device incorporates a number of advanced instructional features which may be tested for their contribution to teaching effectiveness. These capabilities include selective task sequencing; variable task difficulty and complexity; selective malfunction insertion; simulator freeze; rapid re-initialization; automated demonstration; self-confrontation; and a number of methods for providing knowledge of results to the trainee.

The total HRL/FT training research facility includes several devices less complex than the ASUPT which makes it possible to investigate certain research questions using these less complicated and expensive devices. The first of these is the T-4G trainer. This device is a two degree of freedom motion platform trainer with a Singer SPD Electronic Perspective Transformation (EPT) visual system. The image generation system, based on a color movie film, uses a CRT to project an electronically generated horizon display such that an approach, landing and takeoff sequence may be presented as a visual display for the trainee.

Another important item of research equipment is the T-40 trainer. This trainer is an instrument and procedures trainer incorporating a two degree of freedom motion system. It is a side-by-side seating cockpit with an instrument configuration similar to that installed in the T-39 aircraft.

A further research capability in the HRL/FT facility is the Formation Flight Trainer (FFT). This trainer is a fixed base low fidelity part-task trainer which provides some of the essential visual cues for teaching undergraduate pilots the basic formation flight skills. The cockpit has a stick, throttle, rudder pedals and simple instrument displays and the trainer incorporates the rudimentary flight dynamics of the T-38 aircraft. A spherical screen is used to provide a 200 degree horizontal and 90 degree vertical field of view upon which is projected an image of either a T-37 or T-38 model aircraft. The trainee is given the opportunity to practice flying formation from observation of the projected image of this aircraft on the screen.

An important capability of the HRL/FT research facility is the Automatic Data Acquisition and Control System (ADACS), used in connection with the T-4G, T-40 and FFT trainers. This is a system which has as its basic unit a System Engineering Laboratory (SEL) 72 computer. The ADACS is capable of sampling data from the T-40 trainer, the T-4G and the FFT and processing it for up to 29 measurement parameters. The ADACS permits accomplishment of research in the area of recording techniques, performance measures and proficiency measurement using both on-line and off-line techniques. The ADACS facility can be interfaced with the SEL 86 computers which are the core computers for the ASUPT device. Together the SEL 86 computers and the SEL 72 comprise a powerful computational capability for the HRL/FT facility.

Other capabilities within the HRL/FT facility support research both in the determination of training device requirements and in training methods and training device utilization. The first of these is an eye movement recording capability which has been developed by HRL/FT personnel. The device can be used both in aircraft and simulators and is designed to provide data with respect to the information or important content of the display used by the pilot and the required field of view. A second capability is the laboratory's audio-visual instructional media facilities. These are comprised of a video laboratory for the production of video instructional presentations, a series of learning center carrels and the Audio-Visual Instrument Training device (AVIT) developed by Life Sciences, Inc. This latter device has the capability for presenting both visual and audio information, forward and backward branching in both audio and visual modes and interaction with the device by the student both with aircraft controls and multiple choice answer response keys.

A final major and important piece of equipment available to the HRL/FT facility is an instrumented T-37 aircraft. This aircraft is a very important piece of equipment for obtaining basic information relevant to the pilot's overall system performance and is essential to the test of the performance equivalence thesis discussed in Section 4.0. Most importantly, it allows for the correlation of the level of the pilot's performance in controlling system output parameters such as heading and airspeed with control input parameters such as fore-and-aft and lateral stick movements. These measures are essential to establishing a data base for the determination of the equivalence of the ASUPT device to the aircraft being simulated.

## 2.3 Delineation of the High Priority Experiments

Based upon the priority assignment by the panel of experienced individuals and the capabilities of the research equipment and constraints surrounding the research facility, certain experiments and supporting investigations have been delineated. In the delineation of these experiments it was felt that the highest effectiveness possible should be made in the use of the research equipment and personnel. Therefore, a second group of individuals with experience in experimental laboratory and field investigations was selected to provide expertise in how these experiments should be conducted. It was a function of this panel to provide guidance in designing these experiments so that they would be most economical and most effective in attaining results which could be used with confidence in decisions with respect to training procedures and training methods. These experiments are delineated in a later section.

It was also felt necessary to examine the research questions, particularly those having to do with training methodologies and progression of the trainee through the training program, utilizing less complex and expensive devices to the maximum extent possible. It was felt that much information directly useful for improving the effectiveness of the Undergraduate Pilot Training program could be gained through direct use and experimentation with the simpler devices. For example, earlier work with the use of the T-4G simulator in the T-37 Undergraduate Pilot Training program has demonstrated the worth of such devices in determining the contribution of different training approaches. (see Woodruff, Smith & Morris, 1972). They have also proved valuable in the investigation of system performance measures and are recommended to be put to further use in the investigation of operator output performance measurement. The audio-visual capability of HRL/FT along with devices such as the AVIT are important to investigations of training in specific training objectives which form the basis for accomplishing the final training objective for the undergraduate pilot.

## 3.0 PRIORITY RATINGS OF RESEARCH PROBLEMS

The priorities assigned by the panel of experienced training research individuals were used to generate an initial listing of problems judged to be important to increasing the effectiveness of pilot training. This list, taken in conjunction with the capabilities of the HRL/FT facility, provided the basis for deriving a list of recommended investigations.

As was described earlier, the members of the panel were asked to arrive at a listing of the items using a modified paired comparison technique such that high priority items could be identified. This technique is described in detail in the instructions to the raters given in Appendix C.

The median ratings for the items were computed and are tabled in Appendix D, along with their semi-interquartile range (Q) values. An abbreviated list in judged order of importance is given in Table 3.1. This list is derived from the panel list and considerations of administrative, scheduling and equipment constraints. It will be discussed in detail in later sections.

Table 3.1

Abbreviated List of First Priority Research Questions
Formulated on Basis of Multiple Criteria

1. Motion-Vision Interaction
2. Content of the Visual Display
3. Sequencing of Training Tasks
4. Cognitive Pre-Training
5. Individualized Instruction
6. Feedback
7. Instructor Training
8. Contextual Training

In considering the items in these lists an examination of the semi-interquartile range values listed under the Q column is in order. These values reflect the variability among the ratings for the several items. They show considerable variability in the ratings of the items given by the panel members. To a great extent, this variability arises from genuine differences of opinion among the raters as to which problems are more important for solution in improving the effectiveness of pilot training. However, some of the variability comes from the seemingly inescapable intrusion of other criterion into the rating procedure. Since the panel members have been working first hand with on-going training programs and carrying out training research in operational settings, they found it difficult in some cases to assign priorities on a purely detached "contribution to training effectiveness" basis. For example, some judges felt that certain items required more effort in pulling together relevant information in the literature and in applying that information to the problem. The feeling was that if this were done, the item would not command a high priority in an on-going research program. Some judges felt that certain items were so important on other bases, such as pilot acceptance, that it would not be worthwhile to expand effort on evaluating them in terms of contributions to training *per se*. Again, some judges felt that for certain items such as aircraft dynamics simulation, the engineering developments were such that research as to its relationship to training effectiveness could not be considered high priority. That is to say, that providing high fidelity in the aircraft dynamics simulation was felt to be so feasible and relatively economical that research on the fidelity of aircraft dynamics simulation was not particularly urgent.

The comments and annotations by the panel of judges in assigning the priorities to the research items are important in interpreting the priority list. However, those items which appear in the top ten of the list in Appendix D are not dissonant with the general conclusions to be drawn from discussions with the individual judges. This is also true of the low priority items in the list.

It was indicated in Section 1.0 that the research investigations to be undertaken as first priority would be selected on the basis of the research priorities assigned by the training problem and other considerations. These additional considerations are: the capabilities of the research facility, the criticality of a question in terms of timely input into the training change process, and administrative considerations such as subject and research personnel availability and practicality in scheduling. These considerations, taken along with the experts' ratings, form the basis for an overall plan for undertaking investigations and the recommending of certain first priority experiments. The plan and the experiments are described in Section 5.0.

## 4.0 METHODOLOGICAL CONSIDERATIONS

### 4.1 General Considerations

There are certain considerations which it is felt should be discussed before arriving finally at a plan for long range training research. The first of these are the difficulties inherent in carrying out classical transfer of training experiments. These difficulties make it advisable to examine alternate methods for obtaining experimental data for use in making decisions about training methods and training devices. The development and test of methods which may provide useful data more economically and in more timely fashion is an area which is recommended as worthy of investigation because of the potential savings in money and time.

The difficulties attendant on classical transfer studies are time, cost and availability of experimental subject trainees. In order to assess adequately the transfer effects of any given variable under study, a representative sample of a class of students is required for each of the experimental groups and the control group. The calendar time required for an experiment can vary from a short period when the effect of training in the simulator upon the performance of a single task is assessed to that time required to train a class in a complete curriculum as would be the case when investigating different sequences of the training tasks. When the experimental question is that of the configuration of the training equipment the methodological problems are somewhat different from those in which the research addresses training methods and equipment utilization. Let us first examine the training methods and equipment utilization research area, since it is here that the classical transfer of training methods are most applicable and will need to be preserved.

The primary problem in the classical transfer approach lies in the cost and calendar time required for transfer to the aircraft after training in the simulator. In order to expedite the acquisition of information relevant to the effectiveness of different training methods and ways of utilizing the simulator, it is proposed that studies be undertaken to establish the full ASUPT simulator as a criterion system to be used in those transfer of training studies investigating training methodology and simulator utilization.

With this approach, it is essential that the ASUPT device be established as a valid representation of the aircraft. In the past this has been done in two major complementary ways. The first of these is to implement the mathematical model of the flight characteristics of the aircraft as accurately as possible in the simulator computer. The second, is to make the general cue environment of the pilot as much like that of the aircraft as possible using the criterion of asking experienced pilots to fly both the simulator and the aircraft and to make judgments as to their similarity. It is proposed that this technique may be strengthened by the use of measurements of the pilots' control performance while flying both the aircraft and the simulator. It is proposed that an estimate of the population distribution of these performance values for the aircraft be established through collection of data in an instrumented T-37 aircraft. The rationale is that, if the experienced pilot flies the aircraft through maneuvers in which specified system measures are required to be within specified limits and it is shown that his control performance in the ASUPT while performing within identical limits is the same as in the aircraft, this is supportive data to the equivalence of the simulator to the aircraft in respects important to pilot control. The outline of a data collection program in the aircraft is discussed in Section 5.2.5.

The method being proposed has been termed the performance equivalence approach to establishing the characteristics of the training simulator. The method constitutes a quantification of the present methods for using the skills and knowledges of highly trained and experienced pilots in making the simulator equivalent to the aircraft in terms of the pilot performance required. Establishing the utility and validity of this technique in the ASUPT investigations will provide the ground work for its use in the evaluation and calibration of other training simulators within the Air Force.

Performance equivalence in terms of operator performance is assumed to be established upon demonstration that his performance under one set of conditions is not different from his performance under a reference set of conditions. That is to say that performance measures of operator output obtained in the instrumented aircraft may be used as an estimate of the population mean ($\bar{x}$) and the standard error about that mean ($\sigma_{\bar{x}}$) for specified measures. Confidence limits may then be set up about the mean to determine whether any other set of conditions, i.e., configurations of the simulator, fall within or without those confidence limits with respect to the performance measures being taken. It is necessary to point out that the performance measures in question must be established as being reliable, discriminating, and logically and meaningfully related to the task at hand.

Once the ASUPT system has been established as being representative of the criterion aircraft and performance equivalence has been established, the system may be utilized as the criterion system for transfer of training experiments in which the aircraft would normally be used. Also, it provides a criterion system for research in situations which are not practical or advisable in the aircraft. These are those which either pose safety hazards or impose unusual stresses on the aircraft.

The question of the generalizability of the findings regarding training methods obtained in this manner may be raised at this point.

It could be held that results as to the comparative effectiveness of different training methods obtained through using ASUPT as the criterion system are not valid for training for transfer to the aircraft. If this thesis were true it would follow that the results could be held not to be valid for use in other simulators as well or that methods used in one training aircraft are not useful in another. Either contention would seem to be contrary to the body of evidence and practice in education and training in which training methods and techniques are valid across a variety of training situations and training materials and are not unique to them.

The second major area in which training effectiveness decisions must be made is that of the configuration of the training simulator. Here again, we may consider the use of the classical transfer of training paradigm and the role that might be played by other methodologies in support of training effectiveness decisions. When carrying out a classical transfer of training study in which the question is being asked as to the relative importance to transfer of training of given levels of the characteristics it is necessary to establish levels of that variable for-experimental study. For example, a transfer of training study might be carried out in which all combinations of degrees of freedom of movement of the simulator are selected as experimental conditions. The number of possible experimental conditions and trainees, as well as the amount of calendar time required for the experiment would be very large (see Smith, 1972). Further, and importantly, it is necessary to carry out prior studies to determine whether each of the levels of the experiment as defined in physically measurable terms is meaningful. These antecedent studies would have the goal of determining which of these physically defined conditions are different in terms of the pilots' performance.

It is evident that many characteristics of a simulator in which we may have a valid interest as to their training effectiveness may be defined in physical units which can be differentiated through use of the appropriate metric but which cannot be differentiated by the operating pilot at the level of his perception and/or performance. This is the classical psychophysical problem in which intervals on the psychological scale bear a relationship to the intervals of the physical scale, but not necessarily one which is linear or even monotonic. In training effectiveness research the levels of a variable being investigated must be set based upon intervals differentiated in terms of performance rather than physical units. The determination of the performance intervals is prerequisite to transfer of training research for many variables of interest. To illustrate further the importance of the psychophysical relationship we may consider the fidelity of motion variable in training simulator research. The degree of fidelity of motion may be defined in physically measurable terms in a variety of ways which could be varied systematically to determine its effect upon transfer of training. Parenthetically, in choosing the physical expression of a variable one should be selected which is meaningful and useful for the simulator design engineer. The fidelity of motion variable may be expressed in terms of the frequency response of the motion platform to some driving function which might be varied over a range of physical values for experimental purposes. However, in this case, as is true in many others, there is virtually no background information to guide the experimenter in setting levels of the experimental variable. As stated earlier, it is necessary, through essentially a psychophysical procedure, to establish discriminable intervals of the variable before considering further experimentation. What must be established are the physical intervals of the variable which are different for the operator in terms of his performance. Like the fidelity of motion variable, a great many variables of research interest require establishing the psychophysical scale before experimentation can proceed.

What is proposed is that prior to the conduct of transfer of training experiments, it is necessary to establish, for many experimental variables, that the conditions or levels of any variable being examined are different in terms of operator performance. Conditions or levels set up on the basis of the physical measurement of the variable may or may not be different in any way meaningful or even perceptible to the pilot. Those levels of the experimental variable which do not differ with respect to performance could not be expected to differentiate with respect to transfer of training. It is to be emphasized that establishing the limits of the physical scale within which performance is equivalent establishes an interval on the performance scale and that levels of the experimental variables must be set on the basis of this scale.

Once the ASUPT has been established as the criterion system a less costly method than classical transfer can be used for obtaining information about the effectiveness of simplified systems. The method rests on the assumptions that transfer of training from the criterion ASUPT is positive and high and that a modification of ASUPT, even though different from the criterion ASUPT in its physical metric, when equivalent to it in terms of pilot performance will provide equally positive and high transfer. Given these assumptions many simulator characteristics which are important to investigate from a cost-effectiveness stand-point may be studied without conducting formal transfer of training experiments.

The minimal system which is equivalent to the criterion ASUPT with respect to any simulator characteristic is just that - the minimal essential physical system which is equivalent in terms of performance to the more complex one. It is assumed that transfer to the aircraft would be as great using that system as with the criterion system. However, other configurations which could be quite unlike the criterion ASUPT in some of its characteristics might be better training configurations. That is, the trainer may be modified in some of its characteristics or additions made to it to enhance its efficiency as a training device.

The point just made leads to making the distinction between efficient training and effective training. Efficient training is that which brings the student to the immediate training goal most economically in the least training time. If the skill attained upon reaching the immediate training goal can be applied in a larger training objective the immediate goal training is effective in terms of the larger goal. For example, if the cues used in approach and landing can be taught more quickly using a highly abstract display we have an efficient training technique. It will be an effective technique only to the extent that the skills acquired by that technique can be applied in the larger more realistic situation, i.e., positive transfer takes place.

We may assume that any training which transfers positively to the ASUPT criterion system is effective training for the aircraft. Or we may not accept as effective any training method, procedure or equipment until it has been demonstrated that positive transfer to the aircraft is the case. The choice is simple but significant with respect to cost. The adoption of the ASUPT as the criterion system for investigation of the most efficient training methods and simulator utilization is believed to involve small risk. In determining the minimally essential characteristics of the training simulator, the use of performance equivalence methods to establish the least common denominator which is equivalent to the ASUPT criterion system appears logically sound. The experimental data to support it are sparse although experience with simulator configurations over the years lends it credence. It only needs to be recalled that all manner of simulator configurations have been used with positive results. What is needed is the systemization of the method for varying those configurations to determine which we might settle upon for use. The transfer of the training from that configuration seems assured. Studies designed to develop and test such an approach are proposed in later sections of this report.

### 4.2 Performance Measurement

In assessing the rate of acquisition of skill or the final level of skill of an operator of a complex system such as an aircraft, performance may be evaluated at two points in the system. These are at the system output point through such measures as heading, airspeed and altitude and at the control input point through measurement of control movements. These measurement points (MP) are shown in Figure 4.1.

It seems a reasonable assumption that an efficient training system would establish in the trainee quickly and economically the control input behaviors of the experienced and skilled operator appropriate to bringing about the specified system output. Training may be thought of as shaping this control output behavior. Knowledge of the level of this behavior as training progresses would be useful to the instructor in guiding the student.

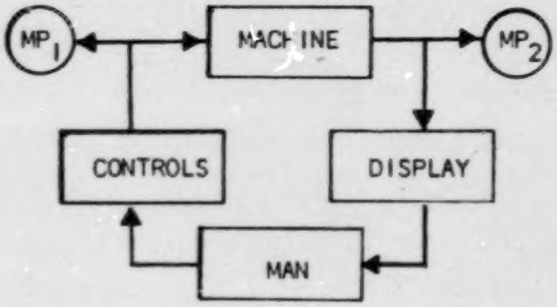


Figure 4.1 Performance Measurement Points (MP) in the Man/Machine System

When all training is given in the aircraft, i.e., the final criterion system, concern with the control input as an index of skill level as opposed to system output is a less important matter. System outputs are available, have been used as measures over a long period of time and a good deal is known about them. (See Demaree, et al., 1964) Concern with the operator output parameters begins when the desire is to train in a simulator the skills required for precise control of a dynamic system such as an aircraft. It is then that system output measures may be misleading since the human operator can adapt his control behavior to bring about the same system output over a broad range of different systems. In this case, the simulator may shape control input behavior not directly transferable to control of the aircraft if the simulator differs in the criterion system in significant ways. It may be possible for the operator to control the system such that the correct system output is obtained while at the same time requiring quite different control inputs - inputs which would then be inappropriate to the criterion system with resulting reduced, or even negative transfer of training.

The emphasis here on measurement of operator output behavior at the control input point is its use in the performance equivalence approach to the investigation of the necessary characteristics of training simulators. With this approach the experienced pilot is a "calibrated" control element being observed to determine whether his control output behavior changes with prescribed changes in the system which he is controlling when system performance is maintained at a prescribed level. What is sought is a measure which is a reliable description of the pilot's control behavior and is sensitive to changes in task conditions such as the dynamics of the system being operated or changes in the sources of his information for controlling the system. An example of the latter is a change in the dimensions of movement of control of the motion platform in an aircraft simulator.

The behavior of the human controller in a complex closed-loop system is exhibited in a complex time varying output through the controls of the system. A simple, direct, and preferably "on-line" summarization of this output is required. Previous work has shown that such measures as the power density spectrum, the breakpoint frequency of the transform of that spectrum and the percentage of power in selected portions of the spectrum are summary measures which reflect meaningful changes in the operator's behavior with changes in the conditions of the task and may be useful measures. (See Norman, 1973 and Matheny et al., 1974) The relative reliability of such summary measures and their inter-relationships need to be established. What is required is an examination and analysis of pilot control output behavior in the complex control situation across a range of conditions of external disturbances to the system and of requirements for control, i.e., maneuvers or tasks. Systems which have the capability for experimental manipulation of variables for studying this behavior and providing answers to practical questions regarding simulation requirements are ASUPT, T-40 and T-4G simulators, and the instrumented T-37 aircraft. The use of these devices in developing such performance measures and in the overall research program is discussed in Section 5.0.

## 5.0 RESEARCH PROGRAM

### 5.1 Overall Plan

The major elements in an overall plan for a research program in undergraduate pilot training are shown in Figure 5.1. This plan includes as a first phase development of procedures, methods and measurement techniques for use of the research equipment. The second phase includes carrying out screening experiments and more formal investigations. The first stage serves to provide a technological base for experimentation and is fundamental to research in the program. It is designed also to produce data applicable to other training research programs and to training research device procurements.

The research phase of the program is divided into investigations of training methodology and of training simulator requirements. Each of these areas is further divided into a screening and a validating phase. The screening phase is designed to narrow down the multitude of variables in a systematic way, particularly with respect to the simulator requirements research area prior to more intensive formal experiments.

It should be mentioned that training methodology and simulator requirements are not mutually exclusive areas of research. Certain

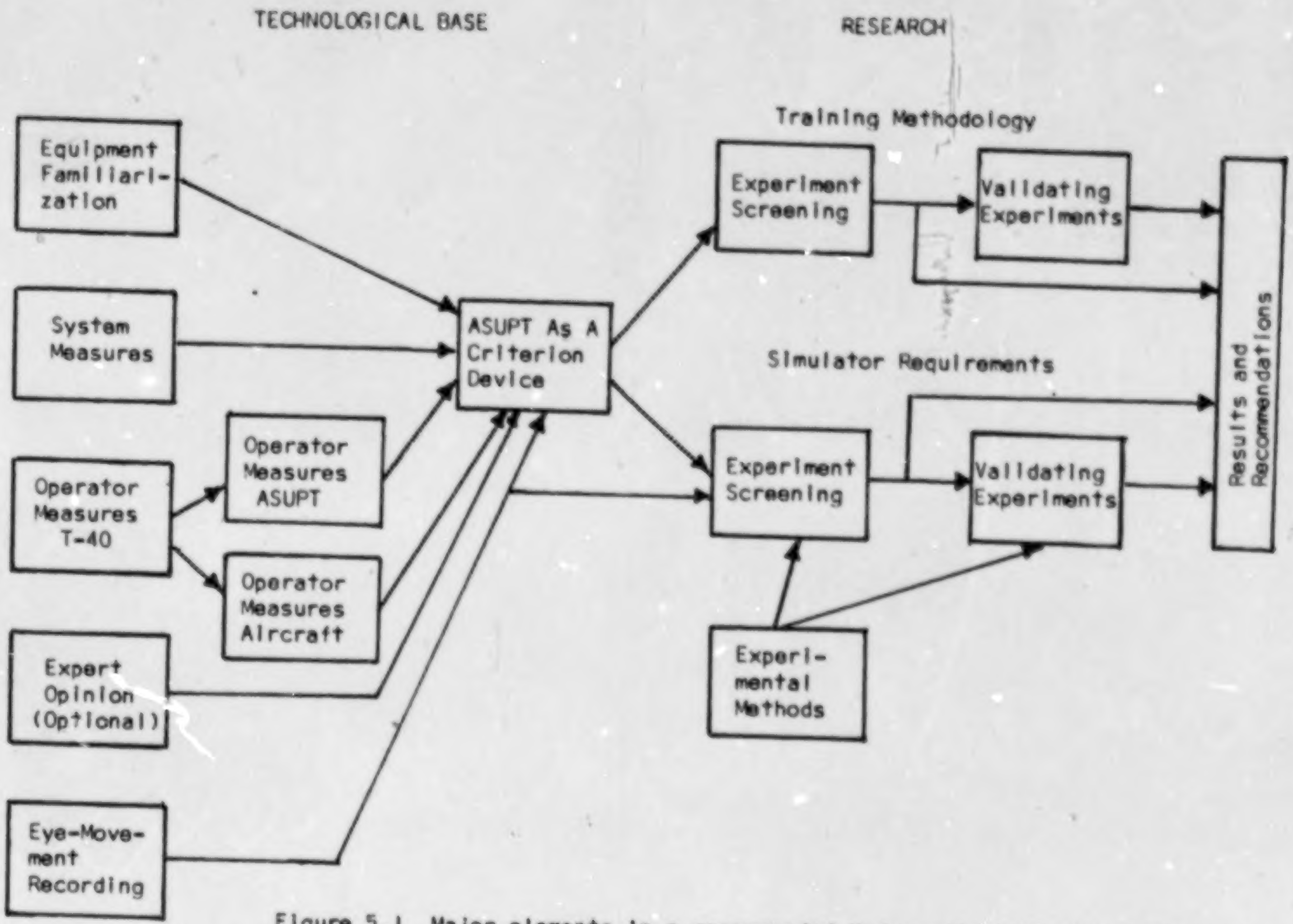


Figure 5.1 Major elements in a recommended Undergraduate Training Research Plan utilizing the HRL/FT facilities

training methodologies will require the use of particular simulator characteristics. Conversely, certain simulator requirements will require the utilization of certain methodologies. It should be noted also that the results of screening experiments may form the basis for recommendations for improving training effectiveness without going through the more formal experimental stage.

The research plan provides for the investigation and test of certain less well used investigative methods with the goal of determining the utility of more economical experimental approaches and designs.

The various elements in the overall research plan are discussed in the sections to follow.

## 5.2 Establishing a Technological Base

Establishing a technological base means simply that the development and test of procedures, measurement techniques, equipment checks and the like are necessary antecedents to carrying out a research program. The technological base discussed here extends beyond this since it recommends a somewhat different approach by proposing to establish the ASUPT as a criterion device for the conduct of investigations and experiments. This phase of the program is intended to provide the data for the characteristics of a training simulator. This performance equivalence approach was discussed in Section 4.0.

It should be pointed out also with respect to establishing the technological base that the working out of procedures, measurement techniques and the like are proposed to be accomplished using specifically designated experimental variables as the vehicle for developing the procedures and techniques. The working through of such an experiment is intended to provide practical information for the technological base as well as to provide useful data on the variables involved, however, limited or preliminary. This experiment is proposed to be one in the simulator requirements research area.

### 5.2.1 Equipment Familiarization

The information to be gained and procedures to be established under this category are concerned principally with experimental equipment characteristics. Here the research personnel will gain familiarity with the problems and procedures in configuring the equipment. Generally, the order of experimental equipment configuration is determined by the experimental paradigm adopted by the researcher. However, in those experiments dealing with simulator requirements using the performance equivalence paradigm the order of experimental conditions may be set up to be most efficient in terms of equipment change rather than overall experimental paradigm. This holds since experienced pilots will be used as subjects and will be trained to specified levels of system output under given experimental conditions. Under this experimental method it is not critical that the conditions be ordered in any particular manner with respect to subject learning. It is possible then to order the experimental conditions in terms of ease of transitioning from one equipment configuration to another rather than in accordance with some overall experimental paradigm. Information obtained as to the most economical way of changing from one equipment condition to another can be obtained during the early equipment familiarization phase and will prove a valuable time saver later.

These preliminary studies and investigations will afford the opportunity for obtaining data on the consistency and reliability of the equipment under continued experimental use. Idiosyncrasies within the system can be identified so that they may be taken into account in planning future experiments.

A necessary concern is with establishing calibration procedures for the important and necessary parameters within the system during experimentation. The type and frequency of calibration necessary to keep the equipment functioning at a standard level for experimental purposes must be established during this phase and provides data for the technological base.

An important function to be accomplished during this phase is the determination of how the experimenters and instructors will function at the ASUPT console or instructors' stations in carrying out the experiments. Since the two instructor stations differ in terms of the information available to the experimenter or instructor, the procedures and practices for providing instructions to the subjects need to be worked out and function smoothly.

### 5.2.2 System Measures

These measures are those referred to as $M_2$ in Figure 4.2 and reflect the performance of the total man-machine system. In aircraft they are such parameters as airspeed, heading, altitude, and pitch or roll angle. It is necessary that these be developed and specified for each of the research devices such as ASUPT, the instrumented airplane and the T-40 and T-4G trainers. The specification of these measures is important throughout all phases of experimentation although their use differs between the training methodology and the simulator requirements areas.

In the areas of precision of aircraft control useful and reliable measures have been developed for most maneuvers both in the simulators and in the aircraft. Criteria against which performance may be measured can also be rather readily established for carrying out the required task procedures.

System output measures are being established by the Human Resources Laboratory, Flying Training Division, through contract and HRL/FT personnel efforts. The HRL/FT effort has been summarized by Waag (1974) in which he points out that the major emphasis in the present performance measurement development is toward developing those measures which reflect performance in the simulator, i.e., ASUPT. Emphasis is placed upon these performance measures since it is assumed that performance in the simulator will be positively related to performance in the aircraft and it is, therefore, possible to use the simulator as a criterion device for investigating hardware configurations and training strategies. The HRL/FT in-house work is also directed toward defining the objectives for any particular maneuver or sequence of training tasks and to develop measures for those particular criteria. A major effort is being directed toward developing measures which will determine the degree to which the criterion objectives are met; reflect only the salient characteristics of performance; are useful by the student and the instructor pilot; and are generated on a real-time basis so that feedback may be immediate.

The systems measurement work being carried out by HRL/FT personnel provides a sound basis for selection of system measures for any given experimental investigation. Life Sciences' efforts have, therefore, been directed toward the development of operator performance measures rather than system measures. It should be noted here, however, that HRL/FT efforts have not been limited solely to systems measures but have also been concerned with operator output measurement.

### 5.2.3 Operator Performance Measures - T-40 Experiment

Operator performance measurement was discussed in Section 4.2 in connection with the performance equivalence experimental paradigm. These measures are taken at the controls operated by the pilot and reflect his inputs into the system. They reflect his direct response to the stimuli presented to him by the system. They are distinguished from system performance records which reflect his response plus the variability in the system through which he is operating.

Investigations in the T-40 training simulator can be designed to examine different procedures for summarizing the time varying operator output into the controls, to examine inter-individual differences in these summary measures and to determine the stability or reliability of these measures over time. This device coupled with the ADACS data recording system constitutes a most suitable device for preliminary investigations of these questions.

As a general condition of the experiments in which operator output measures are being examined, the pilot must control the system to a prescribed level of system performance at which time his control output behavior is recorded. It is necessary to standardize system performance in order that changes introduced into the system being controlled may be reflected in the operator's control output. Control output behavior is then compared across changes introduced into the system or the task being carried out. When such changes do not result in changes in the experienced operator's control behavior, the conditions being studied are concluded to be behaviorally equivalent.

As indicated, the object of the proposed T-40 experiment is to examine the methods for summarizing operator control outputs across different levels of conditions in the T-40 trainer. In this experiment the data of interest are the operators' control outputs for a specified period of time under the given experimental conditions after he has reached a specified level of performance in systems output for that condition. The subject pilot will practice the condition until he has reached the specified performance level on the system output measures of heading, altitude, airspeed, pitch angle and bank angle. The several conditions of the experiment are given in Table 5.1.

Table 5.1

Experimental Conditions for Investigating Performance Measures in the T-40 Trainer

| CONDITION | VARIABLES | | |
|---|---|---|---|
| | TURBULENCE LEVEL | TRAINER MOTION | MANEUVERS |
| 1 | Low | On | St & level |
| 2 | Moderate | On | St & level |
| 3 | High | On | St & level |
| 4 | Low | Off | St & level |
| 5 | Moderate | Off | St & level |
| 6 | High | Off | St & level |
| 7 | Low | On | 30° bank turn |
| 8 | Moderate | On | 30° bank turn |
| 9 | High | On | 30° bank turn |
| 10 | Low | Off | 30° bank turn |
| 11 | Moderate | Off | 30° bank turn |
| 12 | High | Off | 30° bank turn |

The following list of plans and procedures apply to the conditions given in Table 5.1:

1. Trials are two minutes in length.
2. Subject pilots are to be experienced instructor pilots.
3. Subject will practice the maneuver under each condition until he reaches criterion performance on the system specified output measures.

4. System output measures are heading, altitude, airspeed, bank angle and pitch angle.

5. Operator output measures are the subject of the investigation and analysis is performed on the recorded output of fore-and-aft and lateral stick and of throttle.

6. Conditions tabled above are for a single subject. The order of trial conditions may be varied from subject to subject to obtain an estimate of order effect. However, the subject practices each condition to criterion level so this effect should not be significant. It is desirable to space trials and conditions to avoid fatigue and boredom.

7. Subjects repeat the conditions after one day and again after one week.

In this experiment the measures of particular interest are the pilot's control output measures at the time he has reached specified levels of performance on the system output measures. The control measures are derived from fore-and-aft and lateral movements of the stick and movements of the throttle. These movements may be summarized in a number of ways. What is sought is a simple, on-line summarization which reflects reliably the pilot's performance and is sensitive to changes in it. It should reflect changes with practice and level off at the same point at asymptote. Those measures which are proposed to be examined are: Stick force (mean and mean square value): stick Z score and throttle Z score as developed by Dr. W. Waag of HRL/FT for the ASUPT program (the sum of the squared differences between present stick vector position and last stick vector position): stick fore-and-aft and lateral position computed in the same manner as stick Z: the proportion of operator output power below 6 radians and above 2, termed cross-over power (see Norman, 1974): and transforms of the pilot output power spectrum which allow determination of the upper breakpoint frequency of the pilot's output (see Matheny et al., 1974). It is also proposed that the power in narrow frequency bands around 6 radians will be examined for the shift in power as a function of experimental conditions. The results of these analyses will be used to guide the development of operator performance records in the ASUPT and the instrumented aircraft.

### 5.2.4 Operator Performance Measures - ASUPT

It is proposed as a part of the collection of technological base information that an initial experiment be carried out in ASUPT. The principle purpose is the gathering of information about operator performance measures and equipment procedures. However, at the same time, it may provide information and insights about the effects of some relevant variables. This experiment is proposed to repeat the essentials of the T-40 experiment described in Section 5.2.3 with an additional variable termed "visual display". The selection of conditions will be guided by the results of the T-40 experiment once they are available. However, for planning purposes, it is proposed that the variables and levels listed in Table 5.2 be those to be investigated. This experiment becomes one which essentially examines the question of the interaction between the motion and the visual display in the simulator.

Table 5.2

Experimental Conditions for Investigating Operator Performance Measures in ASUPT

| CONDITION | VARIABLES | | | |
|---|---|---|---|---|
| | *Turbulence* | *Platform Motion* | *Visual Display* | *G-Seat* |
| 1 | Low | On | On | Off |
| 2 | High | On | On | Off |
| 3 | Low | On | Off | Off |
| 4 | High | On | Off | Off |
| 5 | Low | Off | On | Off |
| 6 | High | Off | On | Off |
| 7 | Low | Off | Off | Off |
| 8 | High | Off | Off | Off |
| 9 | Low | On | On | On |
| 10 | High | On | On | On |
| 11 | Low | On | Off | On |
| 12 | High | On | Off | On |
| 13 | Low | Off | On | On |
| 14 | High | Off | On | On |
| 15 | Low | Off | Off | On |
| 16 | High | Off | Off | On |

The general experimental paradigm is the same as in T-40 experiment in that experienced pilots would practice each experimental condition to a specified level at which time control outputs would be recorded over a two minute trial for analysis. Although the conditions are the same as those for the T-40 experiment listed in Section 5.2.3, they are repeated here in the interest of completeness.

1. Trials are two minutes in length.

2. Subject pilots are to be experienced instructor pilots.

3. Conditions are to be carried out for both Straight and Level and 30° Bank maneuvers.

4. Subject will practice the maneuver under each condition until he reaches criterion performance on the system specified output measures.

5. System output measures are heading, altitude, airspeed, bank angle and pitch angle.

6. Operator output measures are the subject of the investigation and analysis is performed on the recorded output of fore-and-aft and lateral stick and of throttle.

7. Conditions tabled above are for a single subject. The order of trial conditions may be varied from subject to subject to obtain an estimate of order effect. However, the subject practices each condition to criterion level so this effect should not be significant. It is desirable to space trials and conditions to avoid fatigue and boredom.

8. Subjects repeat the conditions after one day and again after one week.

The contact visual display to be used is the full width of view present in the ASUPT. The content of the display should consist of a definitive horizon line with distinguishing features on the horizon as external referents for a heading index. A ground plane selected from those available in the visual display data bank judged by instructor pilots to be representative of the local terrain will be used.

### 5.2.5 Operator Performance Measures in the Instrumented Aircraft

The need for operator performance data obtained in the aircraft was indicated in the discussion of methodological considerations, Section 4.0. Operator performance output data in the aircraft being simulated is proposed to be used to establish a data base for comparing performance in the ASUPT to that in the aircraft. Data reflecting how the operator responds in controlling the aircraft under representative maneuvers and conditions are fundamental to developing the performance equivalence approach to determining the necessary and sufficient simulator requirements. By way of review, the performance equivalence approach postulates that two systems are equivalent with respect to performance if operator output performance is the same for both systems when those systems are being controlled to the same levels of system output.

The existence of the ASUPT and an instrumented T-37 aircraft presents an unusual opportunity to develop and test more objective methods for stating and evaluating training simulator requirements. The unique capability of the ASUPT of being varied in its characteristics, coupled with the capability for obtaining reliable measures in the aircraft being simulated, makes possible research into the perennial problem of how phychological equivalence can be established between the simulator and the vehicle being simulated in terms which are quantitative and useful to the simulator design engineer.

As indicated in Section 4.0 it is proposed that pilot performance be recorded in the instrumented T-37 aircraft across a representative set of maneuvers and conditions and a data base be established with respect to this performance. It is proposed that summary measures of the time varying output to the control by the pilot be obtained and that these measures be gathered using highly experienced pilots flying each maneuver to a specified criteria. Data will be collected such that the population statistics of mean and variance in performance may be estimated. These statistical values will represent the population values for the parameters under investigation. The operator control performances of interest are proposed to be the inputs into the stick, both fore-and-aft and lateral, and into the throttle.

A further use of the data obtained in the instrumented T-37 aircraft is its use in summarizing the kind of control input behavior exercised by experienced instructor pilots in the T-37. These data can be considered to be the criterion performances toward which the student's behavior is to be shaped during the training process. Continuous monitoring of the trainee's control inputs will provide diagnostic information which may be fed back to the student to influence his rate of learning.

In carrying out the instrumented aircraft flights experienced instructor pilots will perform to specified system output criteria during certain designated maneuvers. System performance measures will be recorded along with the operator's control output performance. System performance measures are to be the same as those recorded in the T-40 and ASUPT experiments and are heading, airspeed, altitude, pitch angle and roll angle. The records of control movements during these performances will be summarized in the same manner as that developed from experimentation in the T-40 and ASUPT. The measurement parameters to be recorded in the aircraft with the ranges, accuracies and sample rates are given in Table 5.3.

The linear accelerometers listed in Table 5.3 are proposed to be mounted orthogonal to each other at a position on the pilot's seat as close to the pilot's head as possible.

The conditions under which data are to be collected are given in Table 5.4. This table must be interpreted in connection with the flight pattern and sequence for recording trials depicted in Figures 5.2 and 5.3 respectively.

### Table 5.3

### Parameters Proposed to be Recorded in the Instrumented T-37 Aircraft

| Parameter | Range | Accuracy | Sample Rate/Sec |
|---|---|---|---|
| Elev Stick Force | 0-30 lb | ±.1 lb | 100 |
| Aileron Stick Force | 0-20 lb | ±.1 lb | 100 |
| Rudder Force | 0-30 lb | ±.1 lb | 100 |
| Elevator Position | -16° - +24° | .5° | 100 |
| Aileron Position | ±15° | .5° | 100 |
| Rudder Position | ±24° | .5° | 100 |
| Throttle Position | Full | .5° | 100 |
| Low Altitude | 0-5m' | ±20' | 10 |
| High Altitude | 0-25m | ±50' | 10 |
| G's | -1G - +5G | ±.1G | 10 |
| Heading | 0-360° | ±1° | 10 |
| Yaw Rate | ±70°/Sec | ±1°/Sec | 10 |
| Trim Tab Position | On - Off | | 100 |
| Pitch Rate | ±90°/Sec | 1°/Sec | 10 |
| Airspeed | 0-300K | ±1K | 100 |
| Roll Rate | ±100°/Sec | ±1°/Sec | 10 |
| Roll Angle | 0-260° | ±1° | 100 |
| Pitch Angle | 0-360° | +1° | 100 |

Table 5.3 (Continued)

| Parameter | Range | Accuracy | Sample Rate/Sec |
|---|---|---|---|
| Right Eng RPM | 0-110% | ±1% | 10 |
| Time | ---- | ---- | 10 |
| Event Marker | Actuated by IP | | 10 |
| Linear Accelerometers (3) | 0±3g | .01g | 100 |
| Angular Accelerometers (3) | ± 2 rad/sec | $4°/sec^2$ | 100 |

Table 5.4

Conditions and Sequencing Data Collection Sorties
in Instrumented T-37 Aircraft Per Pilot

| Sortie | Trial Order* | A/S | Inst/Contact |
|---|---|---|---|
| 1 | A | 200 | Inst |
| 2 | B | 200 | Inst |
| 3 | A | 100 | Inst |
| 4 | B | 100 | Inst |
| 5 | A | 200 | Contact |
| 6 | B | 200 | Contact |
| 7 | A | 100 | Contact |
| 8 | B | 100 | Contact |

* For trial order see Figure 5.3

In the instrumented aircraft it is proposed that data be collected on the maneuvers of climb, descent, straight and level and 30 deg turns. During these maneuvers tolerances will be held as closely as possible to the standard determined for that aircraft. Data will be recorded during the periods shown in Figure 5.2. This scenario assumes that flight data will be collected with the aircraft being flown from Wright-Patterson AFB to a test flight area and that return from that area may be made at low altitude during which additional data on straight and level may be collected. It is proposed that the maneuvers be carried out both on instruments and contact with the contact maneuvers being flown following initial analysis of the instrument data.

A detailed scenario of the data collection flights in the instrumented T-37 aircraft is given in Appendix E. The manner in which it is possible to obtain a sample of sixteen two-minute trials for each of the maneuvers of straight and level and 30 deg bank for two levels of airspeed in counter-balanced order is indicated in Figure 5.3. The arrangement of data collection trials in Figure 5.3 illustrates the order in which the two minute trial segments may be recorded for both straight and level and 30 deg banks during blocks of two sorties so that the two-minute trials for each of the maneuvers may be collected. For example, in sortie one data is collected in order A. Return to Base from the test area may be flown at a 2,000 ft. altitude during which three more two-minute straight and level trials may be recorded. In sortie 2, trials are flown in order B, again with optional data collection.

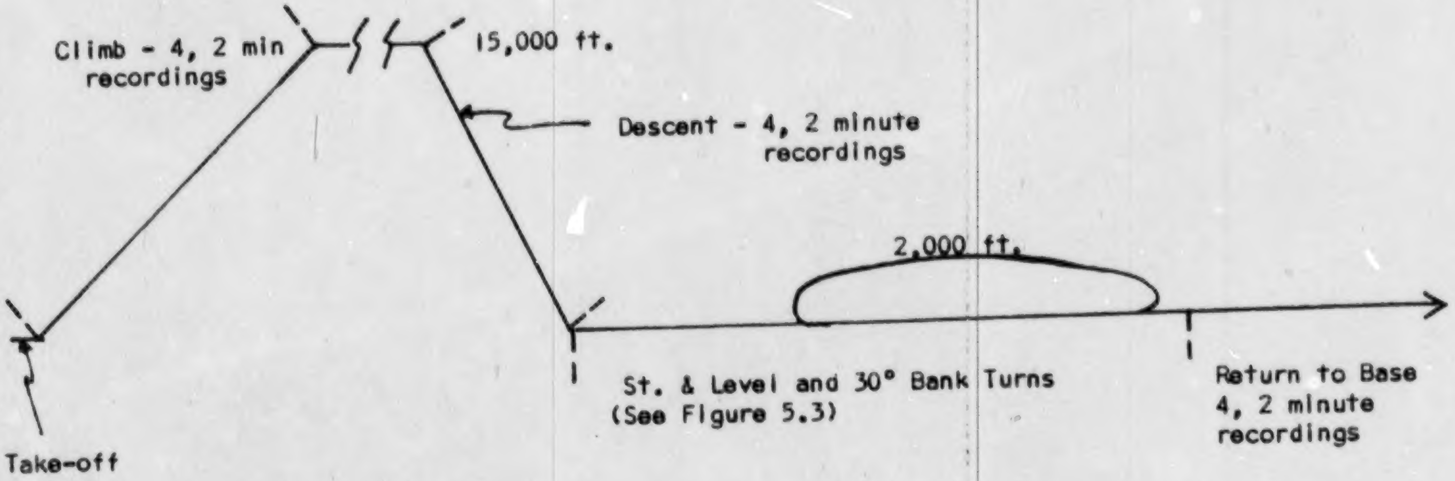


Figure 5.2. Flight pattern for collecting data in instrumented T-37 aircraft.

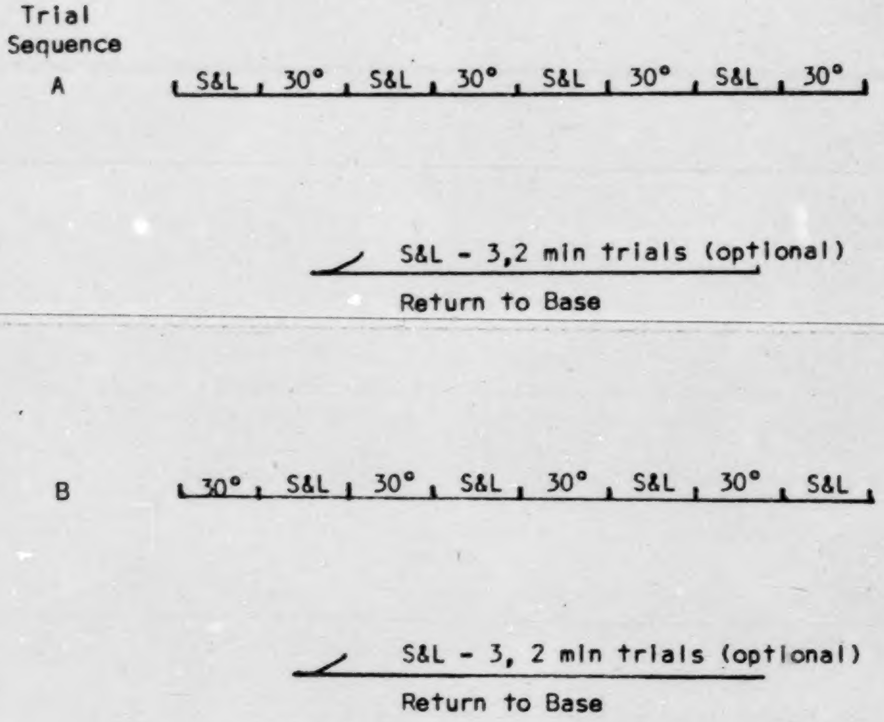

Trial Sequence
A
S&L 30° S&L 30° S&L 30° S&L 30°
S&L - 3,2 min trials (optional)
Return to Base
B
30° S&L 30° S&L 30° S&L 30° S&L
S&L - 3, 2 min trials (optional)
Return to Base

Figure 5.3 Order of trials for each block of 2 sorties for the flight conditions given in Table 5.4.

trials recorded during return to base. Each pilot performs eight sorties in obtaining data on these maneuvers, both on instruments and contact, i.e., those shown in Table 5.4. It is proposed that a minimum of five pilots fly the aircraft data collection sorties and repeat them in the ASUPT simulator. As indicated earlier comparison of the performances in the simulator and the aircraft will allow for adjusting the simulator to be equivalent in terms of pilot performance to the T-37 aircraft.

After completion of data collection under the conditions listed in Table 5.4 data will be collected on maneuvers during which the aircraft is flown closer to the limits of its performance envelope. These maneuvers are stalls and loops. It is proposed that each of the 5 subject pilots fly 8 stalls and 8 loops maintaining as close tolerance to prescribed limits as possible while the parameters listed in Table 5.3 are recorded. It is estimated that this will require two additional sorties.

In summary a total of 8 sorties per pilot will be necessary for complete data collection on climbs, descents, straight and level and 30° bank turns. An additional estimated 2 sorties will be necessary to obtain data on stalls and loops.

The data should be formatted for analysis as follows:

1. Nine track tape.
2. Less than 136 characters per physical record
3. 1600 or 800 bits/inch
4. EBCDIC (Extended Binary Coded Decimal)
5. Even parity

### 5.2.6 ASUPT as a Criterion Device

The development of system and operator performance measures, both in the ASUPT and in the instrumented T-37 aircraft are designed to provide objective data for establishing the ASUPT as a criterion device for research. Establishing ASUPT as a criterion device makes possible its use in investigations of efficient training methods and the minimum essential training simulator requirements. The manner in which it is proposed that this be done is through the performance equivalence approach discussed in Section 4.0.

Performance data collected in the instrumented aircraft provide the data base against which the performance in ASUPT may be compared. It is to be emphasized that the comparability of the two devices is being established with respect to the closed-loop dynamic tracking behavior required of the pilot in controlling the systems. The comparability of the two devices with respect to the procedures whereby other piloting activities are carried out are established on the basis of task analyses and other direct comparison methods.

The performance equivalence approach is used to establish the equivalence of the simulator to the aircraft on the basis of its closed-loop control characteristics sometimes called handling qualities. As indicated in Figure 1 the present method for establishing the simulator as being equivalent to the vehicle being simulated is the use of expert opinion. These opinions are those of the design engineer and the experienced pilot. The aim of the performance equivalence approach is to provide, more objective data through direct comparison of performance both in the aircraft and in the simulator.

## 6.0 RESEARCH OUTLINES

The discussion of suggested research is divided into that concerned with training methodology and that concerned with simulator requirements. Both of these areas are important to improving the effectiveness of the training program. It is postulated, however, that the area of training methodology can have the most immediate and significant effect upon the improvement of flying training programs. The areas of investigation listed in Table 5.1 are discussed in this section with details of the experiments recommended to be conducted.

### 6.1 Training Simulator Requirements Research

The major areas of simulator requirements research judged by the panel to be high priority items were those of (1) the visual display to be used in the simulator, (2) the characteristics of the motion system of the simulator and (3) the interaction of the two. Any research purporting to deal solely with the visual or motion cueing problem must, due to the nature of the process, be considered as a study of the interaction between the motion and the visual areas. Motion-vision interaction studies are discussed in detail in paragraph 6.1.3. The two areas of motion and vision research are taken up separately here solely on the basis of the emphasis placed upon one area or the other in a given research study and does not imply a neglect of importance of the interaction effect. Thus, in the research dealing with motion, emphasis is on the investigation of a wide spectrum of motion variables under certain selective conditions of visual display. In the visual display research area, primary emphasis has been placed upon the content of the visual display and its effect in various training tasks and maneuvers under given conditions of simulator motion. Therefore, in reality all experiments proposed to be undertaken in each of the areas provide information as to the interactive effect of various motion and visual display conditions.

### 6.1.1 Investigation of the Content of the Visual Display

#### 6.1.1.1 Background

The problem of the content of the contact visual display in the simulator received the highest median rating by the Training Problem panel. The importance of the outside world scene in the simulator is underscored by the data collected by J. Brown (1973) from Air Force UPT students and instructors. These data show the traffic pattern to be judged the most critical element of flight instruction, and the most difficult to teach and to learn. A contact visual scene is necessary, of course, for teaching this maneuver in the simulator.

The question as to the appropriate features of the contact world which should be displayed in the simulator has not been adequately answered since the beginning of the use of simulators. Advances in the state-of-the-art have produced several types of complex visual display generation and presentation devices. It is now possible to investigate a broad range of variables and to gain definitive information as to the most effective display content for the training conditions of interest.

Attempts at identifying and describing the visual elements of a display used by a pilot as cues to control of his aircraft have produced both highly complex, and very simple displays. On the one hand very detailed displays have been produced in order to insure that all critical elements are included. On the other hand, some very elemental displays have been used or investigated. Both types are considered by their users to be useful for the purposes intended.

Prior to the completion of the present study, agreement had been reached with HRL/FT that the content of the visual display was an important area of investigation. It was also agreed that during the period of delivery, installation, and calibration of certain research equipment investigations would be undertaken in this area. It is necessary to narrow down the number and levels of the variables through as systematic and valid a procedure as possible before undertaking ASUPT experimentation. This is necessary since the number and combinations of variables possible of being investigated become astronomical without such a screening process. The use of eye movement recordings of experienced pilots flying the undergraduate pilot training maneuvers was proposed as a means of obtaining useful information about the objects and features of the real world scene used by the pilot. (see Figure 5.1) At the same time, data on the dimensions of the field of view being used by the pilot may also be obtained.

Based upon (Bynum et al., 1973) experience with eye-movement recordings and using the visual model for closed-loop control developed by Life Sciences, a program was outlined for obtaining information relevant to the problem of the content of the display. This program was intended as one which would provide useful information upon which to base ASUPT experiments relevant to visual display content, and which could be carried out prior to the installation of the ASUPT equipment. To appreciate how these preliminary investigations support ASUPT experimentation and to relate the eye movement recordings to the visual model, a brief description of the model and the part played by eye movement recordings is in order.

#### 6.1.1.2 A Visual Model as a Basis for Hypotheses

The model referred to has been described elsewhere in Thielges and Matheny, (1971). In brief, the model assumes that external referents in the real world and internal referents fixed to the vehicle being controlled may be projected through perspective geometry upon a picture plane perpendicular to the pilot's line-of-regard. The relationship between the internal referents and the external referents provides information with respect to departures from desired positions of the aircraft in its six degrees of freedom of motion. Different positions of these referents on the picture plane will affect differentially the pilot's ability to discriminate changes in position of the various dimensions of movement of the aircraft. For example, an external and internal referent picked near the vertical mid-line and on the horizon on the picture plane will not allow the pilot to discriminate as fine a change in bank position as if those referents were picked further out on the horizon from the mid-line. Also, referents picked near the horizon do not allow for as fine a discrimination of forward translation as do referents picked closer to the aircraft on the earth's surface, i.e., downward from the horizon line on the picture plane.

It is a tenet of the model that it is necessary for the pilot to select internal and external referents which allow him to make discriminations as to the changes in the attitude and position in space of his aircraft. It is assumed also that a part of the pilot's learning process is the identification of the most appropriate external and internal referents for use in exercising closed-loop control. It is, therefore, necessary not only to identify the appropriate referents in the real-world scene but to describe the "noise" from which these referents must be extracted by the pilot.

#### 6.1.1.3 Eye-Movement Recordings

As mentioned, experience in eye-movement recording (Bynum et al., 1973) led to the belief that such recordings could be used to identify external and internal referents being used by the pilot in the performance of the Undergraduate Pilot Training Maneuvers. Their identification could then lead to recommendations as the variables to be investigated more systematically in the ASUPT complex. Therefore, a program for gathering and analyzing such data was outlined and recommended. The plan for collection and analysis of eye-movement data is given in Appendix F. In that Appendix both content and field of view investigations are discussed since obtaining information in the extent of visual field used by the pilot may be obtained from these recordings. The field of view to be displayed in the simulator is a practical problem about which direct information may be obtained without added cost even though the panel of judges did not rate it particularly high as a research problem.

#### 6.1.1.4 Experimental Approach

It is appropriate at this point to discuss the distinction between the role played by the performance equivalence approach to experimentation and the investigation of the configuration of the visual display for training purposes. As is pointed out in Section 4.0, the performance equivalence approach suggests that by using an highly experienced pilot as a standard controller, that configuration of the visual display which is equivalent to the real world scene in terms of performance can be arrived at through systematically changing physical variables in the ASUPT visual display and observing performance. So long as both system and operator performance are the same as in the aircraft the systems are judged to be equivalent.

As indicated in the discussion of establishing a technological base, the first interest is in the minimally essential set of visual content conditions which are equivalent to performance (system and operator) in the aircraft. Of equal importance is the determination of that visual display which is judged by the performing pilots to be acceptable as representative of the real world scene. The visual display configuration will then be taken as the criterion visual system which may be used in both performance equivalence and transfer experiments. The criterion visual system must be distinguished from those configurations which might be best as aids to training and from that configuration which represents the absolute minimum set of elements for providing the information to the pilot and makes it possible for him to perform as he does in the aircraft.

With respect to training, different hypothesis as to how changes in display content should be introduced to produce the most effective trainee progress may be tested systematically using the performance equivalent system as the criterion system. For example, in training the student to discriminate the visual cues for level off and touch down in landing, hypotheses regarding the optimum number and pattern of lines for training in these cues may be tested. Instructional assists entirely foreign to the real world scene may be tested also to point out to the student the most relevant cues to his task of the moment.

It will be recalled that in the study by Payne et al. (1954) it was found that the introduction of an instructional aid in the form of a reference guage on the visual display enabled the student to learn the proper relationships between the approach impact point and horizon line when they were unable to do so without the aid. Such training aids or displays may bring the student more quickly to the point at which he can control the system, (both with respect to system and operator output) as well as the experienced pilot when he (the student) uses the training oriented display. Thus, the training system is made more efficient. However, the final level of skill to be attained is control of the system, with respect to both system and operator output, using the display configuration which was found with experienced pilots to be equivalent to the real world scene if the training system is to be effective.

It may be noted that at this point the assumption may be made that transfer will be positive and high from the equivalent simulator system since performance of like tasks requires like operator performance. However, in Section 6.1.1.5 tests of the relationship of performance equivalence methodology to classical transfer experiment are proposed to be conducted.

### 6.1.1.5 Experimental Investigations

The first four proposed studies of the content of the visual display are shown in Figure 6.1. In brief, they comprise (a) the establishment of the ASUPT as a criterion system, (b) the determination of the transfer from that system to the aircraft, and (c) two studies which are designed to test the performance equivalence approach while obtaining information relevant to two different configurations of the visual display.

In determining the ASUPT criterion system two criteria will be used. These are (1) equivalent performance by experienced pilots both in terms of system and operator output, and (2) consensus of opinion among these experienced pilots that the visual scene in ASUPT is subjectively acceptable as an adequate representation of the real world scene. The methods and measures for determining performance equivalence were discussed in Section 4.0.

Three major variables are proposed to be important in the ASUPT investigation of the visual display. These are (a) the number of objects in the display; (b) the placement or position of the objects in the display; and (c) the "stylization" or amount of detail in each object. The number and placement of objects to be tested can be more completely defined after analysis of the eye-movement data. However, certain guidance for hypothesis formulation can come from the visual model referenced earlier. This model would suggest that well defined external reference points appropriately placed will provide information

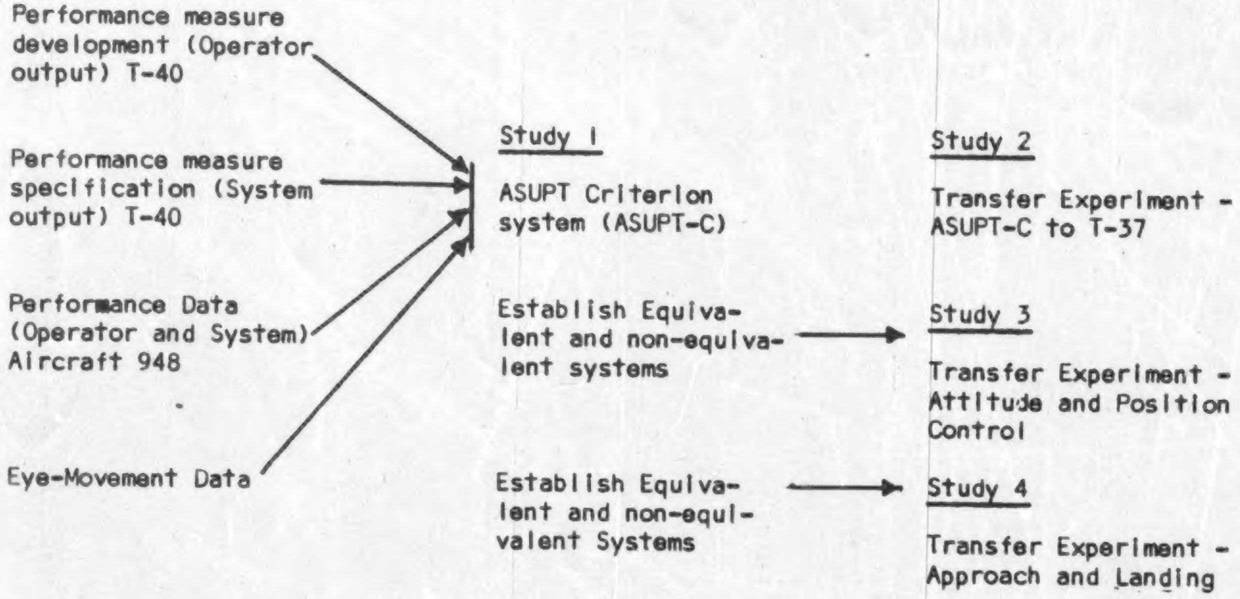

Performance measure development (Operator output) T-40
Performance measure specification (System output) T-40
Performance Data (Operator and System) Aircraft 948
Eye-Movement Data
Study 1
ASUPT Criterion system (ASUPT-C)
Establish Equivalent and non-equivalent systems
Establish Equivalent and non-equivalent Systems
Study 2
Transfer Experiment - ASUPT-C to T-37
Study 3
Transfer Experiment - Attitude and Position Control
Study 4
Transfer Experiment - Approach and Landing

Figure 6.1. Initial Four Proposed Visual Display Studies and Necessary Antecedent Investigations.

to the pilot for control of the six dimensions of movement of his aircraft. Certain positions of the referents are more appropriate to given dimensions of movement than are others.

For control of the three attitude dimensions, pitch control requires a reference object directly ahead of the aircraft on the vertical mid-line and as near to the horizon as possible. For control of this dimension alone, only an identifiable point or object is required. This obtains as a general rule for the control of pitch across all of the maneuvers to be flown. However, for each particular maneuver the placement of the reference object with respect to the ground or sky plane is specific to that maneuver in order for it to be accomplished best. For straight and level flight a pitch reference point ahead of the aircraft at the level of the horizon line, or the horizon line alone, will provide a reference against which the pilot can judge some internal referent on his aircraft in order to hold his pitch attitude. For a nose down attitude during approach to landing a reference object lower on the ground plane would be hypothesized to be preferable.

For bank control, objects displaced laterally from the longitudinal center line of the aircraft provide greater amounts of positional displacement per unit of bank as they move further out from the center line. Thus, an object placed on the horizon at the vertical mid-line would exhibit little perceptible movement to the pilot per unit of bank. That same object placed 30 deg in azimuth from the vertical mid-line would provide a greater amount of displacement for the same amount of aircraft bank and thus enable greater precision of control.

With respect to heading control, objects on the horizon in the forward viewing area to which the pilot can relate an internal referent will provide the same amount of displacement on the display per unit of heading change. However, for ease of scan for the pilot the object should be directly forward on the vertical mid-line and on the horizon.

For the detection of longitudinal motion of the aircraft objects directly in front of the aircraft which appear to move toward it are necessary for the best detection of this movement. Objects directly below the aircraft have a greater perceived displacement while those directly forward and on the horizon have the least per unit of longitudinal movement. Therefore, to maximize the pilot's detection of forward motion or change in that motion objects as nearly beneath the aircraft as possible provide the greatest information for control of this dimension.

The control of lateral displacement parallels that of longitudinal. For discrimination of displacement along the vertical axis the pilot must discriminate changes in the size of objects in that he must discriminate changes in the relative distance between one edge of an object and another or the change in distance between objects.

The cues just discussed are those which allow the pilot to control the attitude of his aircraft about its three axes and to discriminate whether it has changed its position in three dimensional space. In order to successfully fly his aircraft, however, he must discriminate and identify objects in the real world which allow him to direct his aircraft purposefully from point to point or in the fulfillment of some objective or mission. Those objects which he must identify and use for direction of his vehicle are unique to his purposes and objective of the moment. Thus, when the objective of the pilot is to land the aircraft on a particular spot the characteristics of that spot necessary for him to identify it must be present in the display. Similarly, he may be controlling his aircraft in three dimensional space to keep it positioned upon another aircraft during formation flight. The relevant cues peculiar to the other aircraft which allow him to maintain his position must be presented in the visual display in order for the trainee to practice in their use and become proficient in formation flying.

It is the overall goal of research in simulator visual displays to identify those essential cues which allow the pilot to control the attitude of this aircraft and to position it in three dimensional space in accordance with the objectives and goals of the moment. Further, it is the objective of that research to determine what assists or instructional aids may be added to the visual display to enhance the student's attainment of proficiency in the use of these cues. It is the function of maneuvers in the pilot training syllabus to practice the student in the accurate attitude and positioning control of his aircraft. Certain maneuvers have specific and universal objectives such as landing the aircraft. However, in the main, maneuvers are not practiced for maneuvers' sake but rather to practice the student in control of the various dimensions of movement of the aircraft over which the student must have control in order to accomplish specific objectives and purposes. Therefore, it is suggested that the visual display for the beginning student must be composed of that essential set of features which allows him to exercise control about the aircraft axes and along three dimensional space axes as a general set of skills. He must then learn to extract from the real world scene objects which serve him in carrying out his control and navigational functions. He must learn also to discriminate these referents when they are buried in visual "noise". The term visual noise is used here to mean conditions in the real world environment which tend to obscure or make difficult to discriminate the referents which the pilot wishes to use. Atmospheric attenuation, smoke, haze or any condition which causes an object to have low definition constitutes such noise. To the extent that this noise degrades the pilot's discrimination of changes between the referents which he is using to control his aircraft his precision of control must be degraded.

The analysis of the eye-movement records will provide relevant data for identifying the characteristics of those objects which must be identified to attain the goals of the pilot and to identify those factors in the environment which tend to inject noise into the visual scene. The objects which must appear in the visual display to allow him to exercise attitude and position control are not of necessity local terrain features and could be quite abstract. However, it will add appreciably to the realism and, therefore, the acceptance of the display if they are recognizable as local features.

The identification and discrimination of changes among objects may be hypothesized to be a function of the level of detail of the object and its contrast with the background. These factors are controllable as experimental variables in ASUPT and may be varied systematically through the use of the number of lines used to define an object and the shades of gray used to provide contrast between objects or between objects and background (figure-ground contrast).

In the light of the above discussion the first experiments dealing with the content of the visual display are divided into the two categories of (1) that content necessary for control of the attitude and position of the aircraft in three dimensional space, and (2) those relevant to the identification and use of features of the environment which allow the pilot to control his vehicle in attainment of some specifiable goal or purpose. Results from the first of these will be appropriate to the specification of displays for simple basic aircraft control trainers. The results from both provide information for specification of more complex mission oriented trainers. The variables and their levels for studying attitude and position control are given in Table 6.1.

This experiment illustrates the necessity for establishing the discriminable intervals of a variable before going into the experiment proper. In the choice of the shades of gray for any object it is evident that if shade of gray is to be varied over several levels those levels must be chosen which are discriminably different by the subject. Should any two levels chosen not be discriminable it follows that they actually represent one level of the variable to him.

The discriminable levels of gray may be established quickly simply by asking the subject to fly the display while observing the shades of gray in specified objects. The shades of gray in these objects are then varied up and down the scale with the subject reporting each time he discriminates a change in shade. This simple psychophysical procedure will serve to establish those intervals minimally perceptible by the subject while he is engaged in his flying task. Establishing these intervals allows the selection of levels of the variable demonstrably different to the subject for use in transfer of training studies.

| Dimension of Control | Display Features | | |
|---|---|---|---|
| | Condition 1 | Condition 2 | Condition 3 |
| Pitch | Horizon line | To be determined through equivalence tests | Criterion ASUPT system |
| Bank | Horizon line | | |
| Heading | Vertical line sub tending 1° visual angle placed each 45° in azimuth on horizon line | | |
| Longitudinal | Grid pattern ground plane | | |
| Lateral | Grid pattern ground plane | | |
| Vertical | Grid pattern ground plane | | |

Note:
1. Grid line spacing to be determined in pretest.
2. Figure-ground contrast to be determined through pretest to provide positive differentiation of figure from ground.
3. All encoding in Conditions 1 and 2 must be experimentally determined in equivalence pretesting to insure non-equivalence for Condition 1 and equivalence for Condition 2.

Table 6.1. Visual display experimental conditions - attitude and position control Study 3.

The second major category of study is the determination of those features of the environment which allow the pilot to change his position or behave relative to those features in some purposeful way. The two major tasks in UPT in this category are (1) traffic pattern, approach and landing, and (2) formation flying. Of these two training problems that of traffic pattern and approach to landing has been researched to a greater extent than that of formation flying. However, recent experiments at HRL/FT using the Formation Flight Trainer (FFT) has provided directly applicable data to the specification of trainers for training in this maneuver.

The ASUPT visual display capability allows the study of the relevant referents to be presented for the touchdown phase of the landing and how they may be encoded in the display. Satisfactory study of this area has not been possible up to this time. The ASUPT capability makes it possible.

The variables and suggestions for their encoding for the approach and landing study are given in Table 6.2. It is proposed that the essential features listed under Conditions 1 and 2 in both Tables 2 and 3 may be better defined after analysis of the eye-movement records and the full capability of the ASUPT for providing display features has been completely checked out.

The procedure for establishing the ASUPT criterion system in Study 1 has been discussed in Section 4.0, Methodological Considerations. Study 2 will employ the classical transfer of training paradigm discussed by Gagne, Foster and Crowley (1948).

Studies 3 and 4 are proposed as tests of the performance equivalence approach as well as to assess the transfer to the aircraft of less complete visual systems. The parameters of number, position and stylization of objects will be varied so that (1) a condition not equivalent to the criterion ASUPT is obtained and (2) a condition equivalent to the criterion ASUPT system is obtained. This is to be done in the manner described in Section 4.0 using the performance of experienced pilots. Classical transfer of training experiments are then proposed to be conducted using Conditions 1 and 2 of these studies to determine whether the hypothesis that equivalent systems bring about the same amount of transfer while non-equivalent systems do not. The amount of transfer obtained earlier in Study 2.

The general design format for Studies 3 and 4 is shown in Figure 6.2.

## Table 6.2

## Visual Display Experimental Conditions - Approach and Landing Study 4

| Dimension of Control | Display Features | | |
|---|---|---|---|
| | Condition 1 | Condition 2 | Condition 3 |
| Pitch | Horizon line | To be determined through equivalence tests | Criterion ASUPT system |
| Bank | Horizon line | | |
| Heading | Vertical line subtending 1° visual angle placed each 45° in azimuth on horizon line | | |
| Longitudinal | Grid pattern, runway outline cross stripes each 100 yards | | |
| Lateral | Grid pattern, runway edges and runway centerline | | |
| Vertical | Grid pattern, runway edges and cross stripes | | |

Notes:
1. Cross stripe spacing may be modified after pretest.
2. Figure-ground contrast to be determined through pretest to provide positive differentiation of figure from ground.
3. Encoding in Condition 1 and 2 must be experimentally determined in equivalence pretesting to insure non-equivalence for Condition 1 and equivalence for Condition 2.

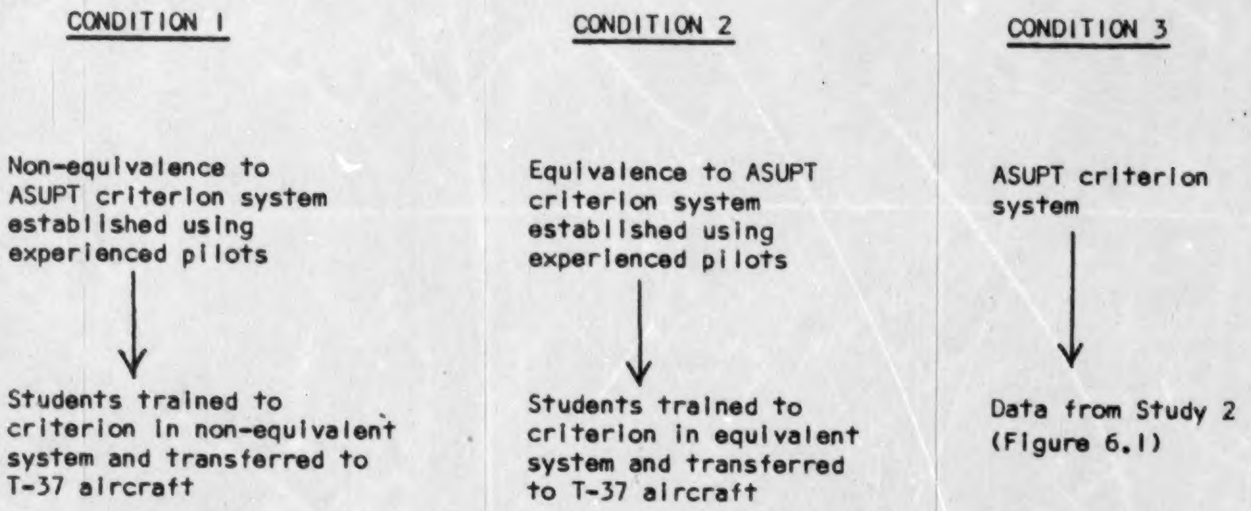

CONDITION 1
Non-equivalence to ASUPT criterion system established using experienced pilots
Students trained to criterion in non-equivalent system and transferred to T-37 aircraft
CONDITION 2
Equivalence to ASUPT criterion system established using experienced pilots
Students trained to criterion in equivalent system and transferred to T-37 aircraft
CONDITION 3
ASUPT criterion system
Data from Study 2 (Figure 6.1)

Figure 6.2 Design format for visual display studies 3 and 4.

### 6.1.2 Investigations of Motion in the Simulator

#### 6.1.2.1 General

The problem of determining the necessary degrees of freedom of cockpit motion in training simulators was sixth on the priority list of training problems. (See Appendix D) Manipulation of this variable in experimental investigations is particularly easy using the ASUPT. This device also has additional areas of interest to trainer motion design - that of gravity alignment and the G-seat. Gravity alignment cueing is designed to come from tilting the platform such that normal gravity is used to substitute for the acceleration or decleration of the aircraft particularly during take-off or landing G-seat cueing is of two forms - those which come from movement of the elements of the seat to provide movement cues and those which provide sustained pressures to the student's body. See Appendix B for more complete definitions.

As pointed out by Smith (1972) it is manifestly not possible or sensible to attempt to investigate all of the possible combinations and permutations of the six degrees of freedom of motion, gravity alignment and the ways in which the G-seat may be used. A sorting out on the basis of the characteristics and dynamics of the physical system being simulated and of the human sensory system was felt necessary and has been done. Further screening of these variables is proposed to be carried out in pretest investigations as indicated in Figure 5.1.

The combinations of conditions selected for recommended study and listed in Table 6.3 may be used either in classical transfer experiments or they may be approached through the performance equivalence method. In the discussion to follow the performance equivalence method is used although the fact of the previous statement must be kept in mind.

#### 6.1.2.2 Experimental Studies

The specific experimental question to be addressed by these investigations is "under what method of introducing motion cues and across what conditions of flight are the control performances of experienced pilots equivalent?" The approach taken supposes that if two systems are measurably different by some quantitative metric but their operation results in no measurable difference in the performance of experienced pilots then the physical differences are behaviorally equivalent and are not different for purposes of a training simulator. This is the methodology discussed in Section 4.0.

The independent variable of prime interest is that of the motion cue condition. What is sought is a determination of whether pilot performance varies as a function of motion cue conditions across different maneuvers and for different levels of external disturbances. The motion cues to be investigated fall under the three broad categories just discussed:(a) platform motion, (b) gravity alignment and (c) G-seat. Particular combinations of sub-categories of these major areas have been selected to obtain data about ten specific questions. These conditions are listed in Table 6.3. The specific experimental questions are given in Table 6.4.

Table 6.4 shows the experimental conditions relevant to providing information about particular experimental questions. The experimental procedure is one in which the twenty-two conditions may be run in three experimental sessions and provide information relevant to the ten experimental questions posed. The experimental questions have been selected such that successive data runs can be made with experimental conditions on subsequent runs being dependent upon the findings of earlier runs. A "sorting out" procedure is used in which the various combinations of conditions are examined to determine whether they effect any differences in pilot performance and what the relative contribution of the conditions are to performance variability. The effects found under one set of conditions are used to guide the selection of the experimental conditions to be used in the next run. In order to accomplish this it is proposed that the incremental design outlined by Demaree in "A Recommended Design for Experimental Studies Using ASUPT" be used. This paper is given in Appendix H.

Under the proposed experimental procedure as outlined in Table 6.4, the first experimental question would incorporate experimental Conditions 1, 10, 11, 15, 16, and 17. Results from performance under these conditions are intended to show whether or not the major conditions of simulation of (a) no motion, (b) six degree of freedom platform, (c) six degree of freedom platform with gravity alignment, (d) six degree of freedom platform with full G-seat, (e) six degree of freedom platform with full G-seat and gravity alignment, and (f) full G-seat only, differentially affect performance and, if so, what the relative effects are.

However, as a test of the performance equivalence approach it is proposed that Conditions 1 (no-motion), 9 (full motion), and that condition found to be equivalent to full motion be used in the paradigm shown in Figure 6.3.

In this paradigm equivalence and non-equivalence is established by the methods outlined in Section 4.0. In Figure 6.3 the condition of no-motion is assumed to be non-equivalent to the ASUPT criterion system in terms of performance. It is also assumed that a condition of less than the full criterion ASUPT system may be established.

If Experimental Conditions 1 and 10 differentially affect performance Session Two will be concerned with obtaining data on Experimental

Table 6.3

Experimental Conditions Selected for Test in Determining Platform Motion and G-Seat Operation

| Experimental Condition | Condition Description* |
|---|---|
| 1. | No Motion |
| 2. | P,R (Platform) |
| 3. | P, R, Y (Platform) |
| 4. | P, R, Y, H (Platform) |
| 5. | P, R. H (Platform) |
| 6. | P, R, H, L (Platform) |
| 7. | P, R, H, F & A (Platform) |
| 8. | P, R, H, L, F & A (Platform) |
| 9. | P, R, Y, H, L (Platform) |
| 10. | 6 Degree of Freedom Platform |
| 11. | 6 Degree of Freedom Platform with Gravity Alignment |
| 12. | P, R (Platform) with Gravity Alignment |
| 13. | P, R, H (Platform) with Gravity Alignment |
| 14. | P, R, Y, H, L (Platform) with Gravity Alignment |
| 15. | 6 Degree of Freedom Platform with Full G-seat |
| 16. | 6 Degree of Freedom Platform with Full G-seat and Gravity Alignment |
| 17. | Full G-seat only |
| 18. | P, R (G-seat), H (Platform) |
| 19. | P, R (Platform(, H (G-seat) |
| 20. | P, R (G-seat) |
| 21. | P, R, F & A (Platform) |
| 22. | H only |

*Legend:

P - Pitch
R - Roll
Y - Yaw
H - Heave
L - Lateral
F&A - Fore-and-aft

Table 6.4 Experimental Conditions for Test of Specific Questions

|  | EXPERIMENTAL CONDITIONS |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| EXPERIMENTAL QUESTION | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 |
| 1. Major areas of simulation | X |  |  |  |  |  |  |  |  | X | X |  |  |  | X | X | X |  |  |  |  |  |
| 2. Minimum degrees of freedom |  | X | X | X | X | X | X | X | X | X |  |  |  |  |  |  |  |  |  |  | X | X |
| 3. Gravity alignment contribution - maximum platform |  |  |  |  |  |  |  |  |  | X | X |  |  |  |  |  |  |  |  |  |  |  |
| 4. Gravity alignment contribution - nominal platform |  |  |  |  | X |  |  |  |  |  |  |  | X |  |  |  |  |  |  |  |  |  |
| 5. Gravity alignment contribution - maximum platform plus G-seat |  |  |  |  |  |  |  |  |  |  |  |  |  |  | X | X |  |  |  |  |  |  |
| 6. Gravity alignment contribution - minimum platform |  | X |  |  |  |  |  |  |  |  |  | X |  |  |  |  |  |  |  |  |  |  |
| 7. Longitudinal acceleration cue contribution - maximum platform - gravity alignment or fore and aft |  |  |  |  |  |  |  |  | X | X |  |  |  | X |  |  |  |  |  |  |  |  |
| 8. Substitute gravity alignment for fore and aft - maximum platform |  |  |  |  |  |  |  |  |  | X |  |  |  | X |  |  |  |  |  |  |  |  |
| 9. Substitute gravity alignment for fore and aft - minimum platform |  |  |  |  |  |  |  |  |  |  |  | X |  |  |  |  |  |  |  |  | X |  |
| 10. G-seat substitution for platform | X |  |  |  |  | X |  |  |  |  |  |  |  |  |  |  |  | X | X | X |  |  |

| CONDITION 1 | CONDITION 2 | CONDITION 3 |
|---|---|---|
| No-motion-non-equivalence to ASUPT criterion system established using experienced pilots | Equivalence to ASUPT criterion system established using experienced pilots | ASUPT criterion system |
| Students trained to criterion on this system and transferred to aircraft | Students trained to criterion on this system and transferred to aircraft | Students trained to criterion on this system and transferred to aircraft |

Figure 6.3 Paradigm for test of performance equivalence method for simulator motion requirements.

Conditions 2, 3, 4, 5, 6, 7, 8, 9, and 21. The results from these conditions are intended to determine what combination of degrees of freedom of motion of the platform are equivalent.

Experimental question No. 3 is answered by comparison of Conditions 10 and 11 with experimental run 1. This question concerns the contribution that the gravity alignment cue makes to the maximum degree of freedom platform.

In Experimental Session 3 the six remaining experimental conditions of 12, 13, 14, 18, 19, and 20 are added. Comparison of Experimental Condition 13 with Condition 5 is intended to answer the question with respect to a contribution of gravity alignment given a nominal platform. What constitutes a nominal platform has been assumed to be that represented by Condition 5, i.e., one with pitch, roll and heave. However, the results of the analysis of Experimental question 2 may change what is considered to be a nominal platform and, therefore, change these conditions somewhat.

Comparison of Conditions 15 and 16 is designed to give information about the contribution of gravity alignment when the maximum platform is used with the G-seat.

Addition of Condition 12 allows the comparison between Condition 2 and 12 and gives information about the contribution of gravity alignment with the minimum platform, i.e., one which provides only pitch and roll stimuli.

The addition of Condition 14 allows for a comparison of that condition with Conditions 9 and 10 and gives information about the longitudinal acceleration cue contribution when a maximum platform is used, i.e., whether the gravity alignment or fore-and-aft translation is the better clue or whether it has any effect at all upon performance.

In carrying out the experimental runs it is proposed that the experimental conditions be carried out under instrument flight conditions using the maneuvers of straight and level flight, 30° bank turns and unusual attitudes. It is also proposed that the fundamental nature of the control task required of the pilot in performing these tasks is a function of the external forcing function or turbulence acting upon the system. His control behavior will be affected by the nature of this disturbing function and it is, therefore, proposed that three levels of disturbance be imposed upon each of the basic flight tasks in order to determine the equivalence of various physical systems across representative tasks and disturbances. The level of disturbance for each condition is to be determined through pre-testing of the turbulence generation system of the ASUPT.

### 6.1.3 Motion-Vision Interaction Studies

#### 6.1.3.1 General

The results of certain experiments conducted in the visual and motion areas are proposed to be used in experiments designed to provide information about the interactive effects of these two major variables. These experiments are proposed to be conducted using the two major areas of visual cueing discussed in Section 6.1.1. These are aircraft attitude control and aircraft position control. Within these two areas experiments are designed to determine whether differential interactive effects occur.

#### 6.1.3.2 Experimental Studies

As mentioned, the interactive effects of motion and vision are proposed to be investigated in two rather different areas of pilot tasks. First, are those conditions in which the pilot's task is control of the attitude of his aircraft. This control is primary and antecedent to control of the position of the aircraft in three dimensional space.

It is hypothesized that the interactive effect is influenced by numerous variables in the total task situation. Primary among these variables are level of precision and control required and the nature of the external forcing functions (ordinarily termed turbulence) imposed upon the system.

The model of control behavior adopted in considering aircraft attitude control is that of the Effective Time Constant ($t_e$) of the system. (Matheny & Norman, 1968) This model is used as a basis for understanding the interactive effects as well as to form predictive hypotheses to be tested. In brief, the model assumes that the precision of closed-loop error-nulling behavior is a function of the immediacy of feedback to the controlling operator, e.g., the pilot. The time taken for feedback to occur has been termed the Effective Time Constant of the man/machine system. The value of $t_e$ depends upon the values of given properties of the machine dynamics and of the human controller. The properties of the human controller of importance are the modalities through which the information is received and the threshold level of those modalities.

The relevance of this model to the motion/vision interaction problem is that certain information about the status of the aircraft, particularly changes in attitude of the aircraft, are transmitted more immediately as feedback to the operator through the motion senses than the visual. It is a tenet of the model that the motion senses are cued by rates of onset of acceleration which allow for the initiation of response much in advance of that which would be triggered by the resulting positional change of the stimulus detected by the visual sense. It follows from the model that increasing the gain on a given display to a particular sense will increase the immediacy of the feedback to the operator. Thus, increasing the gain of the visual display will result in an increase in the precision of control. Likewise, visual displays which provide the operator with rate, acceleration or onset of acceleration information allow him to receive more immediate information as to the status of the system relative to the desired state and to control it more precisely.

From the Effective Time Constant model the prediction can be made that in systems such as the T-37 aircraft, performance of the precise attitude control task will be enhanced by addition of the proper motion cues while other tasks such as positional control in which the visual feedback is timely and adequate will not benefit greatly from the addition of motion cues. It can be further predicted that the visual display which incorporates the higher gain (e.g., large contact display) will result in a higher precision of control. It can also be hypothesized that training a student to a given level of proficiency without those motion cues which will be present in the transfer tasks constitutes over training him and he will do very well, i.e., transfer will be high, when he is transferred into the task in which the total set of stimulus cues are available.

As mentioned earlier the first interaction experiments are designed to examine the situation in which interaction effect is likely to be greatest as predicted by the effective time constant model. This area is in that of close precision attitude control. The experimental conditions suggested for this experiment are given in Table 6.5.

It is proposed that the performance equivalence paradigm be used for this experiment. Experienced pilots will fly each of the conditions and tasks to determine whether or not their output control behavior is different under the various conditions given standard system output performance requirements. For those conditions found to be equivalent and those found not to be, it is proposed that groups of the students be trained under each condition and subsequently transferred to the aircraft as a further test of the performance equivalence approach.

Table 6.5

Experimental Conditions for Initial Motion-Vision Interaction Experiments

| | |
|---|---|
| Tasks: | Approach to landing.<br>Straight and level. |
| Variables: | Motion - no motion and full 6 degree.<br>Turbulence - high and low.<br>Precision of control - high and low. |
| Subjects: | Experienced pilots for establishing performance equivalence. Trainees for training on selected conditions and transfer to T-37 aircraft. |

## 6.2 Training Methodology Research

As indicated in the introductory section, this area of research is proposed to have high potential for producing results which will greatly increase training effectiveness and has immediate application. The adoption of ASUPT as a criterion system for investigating efficient training methods is the basis for this proposal. This is particularly true of research in two areas judged to be important by the training problems panel; namely, cognitive pre-training and feedback. These two areas will be discussed first followed by recommendations regarding the areas of sequencing of training tasks, contextual training and individualized instruction.

### 6.2.1 Cognitive pre-training

Cognitive pre-training refers to the complete understanding of the cognitive and action aspects required for completion of a task before that task is attempted in the simulator or aircraft. In practice it may be achieved in several different ways.

For the perceptual and cognitive aspects of tasks, such as learning to scan, read and interpret the instruments for instrument flight or learning procedural sequences, a number of instructional aids such as photos, work books, or audio-visual devices may be hypothesized to provide effective training in these task aspects. Cognitive understanding or mental pre-practice may be highly effective pre-training for continuous control tasks through use of simple or even no equipment at all.

It is proposed that the evidence is sufficient to support institution of certain forms of pre-cognitive training directly into the training program. These involve those techniques demonstrated to be efficient by Flexman, et al. (1950) and Flexman, et al. (1954). In general these techniques require the student to become proficient in his ability to verbalize the pertinent cues and responses necessary to meet the requirements of the task. In this verbalization it is important that the instructor determine whether the student is merely "parroting" the words of the instructor or whether he completely and thoroughly understands the perceptions and responses that are required for successfully accomplishing the maneuver. With the advent of increasing initial and maintenance costs of simulators, the investigation of the amount of time which might be saved in reaching criteria in the ASUPT simulator for certain maneuvers through the use of other pre-cognitive training methods is highly recommended.

The Human Resources Laboratory/Flying Training Division has as a part of its research capability an audio-visual instrument training device (AVIT) with a program suitable for pre-cognitive training in scanning, reading and interpreting the basic instruments for basic instrument flight. The contribution of this device to reduction of simulator training time for learning the basic flight maneuvers capable of being taught by the device should be investigated. The device is configured to teach a student to scan, read and interpret his instruments for straight and level flight, 30° bank turns and unusual attitudes. A functional description of the device is given in Appendix G.

It is proposed that an experimental group be taught to criterion level in the AVIT device and compared to a control group taught only in the simulator in terms of time to reach proficiency in the simulator. It is proposed that both the experimental and the control groups then be taught all other maneuvers in the basic instrument flight curriculum to determine the degree of generalization from the three maneuvers taught in the AVIT to other maneuvers performed in the simulator.

It is proposed also that the capability for a device such as the AVIT be investigated for its use in teaching the perceptions required in contact maneuvers such as the approach to landing. This hypothesizes that the major portion of the learning task of the pilot trainee is the learning of the perceptual and cognitive aspects of the task as opposed to the motor responses he is required to make. It is hypothesized that once the pilot has learned to perceive the desired stimulus relationships, to recognize departures from these desired relationships and to know in which direction he should initiate control movements in order to correct them his training time in the actual performance of the continuous time varying task will be greatly reduced.

In brief, it is recommended that the use of a programmed branching audio-visual instrument trainer be investigated for teaching the perceptual and cognitive side of contact tasks since these tasks are among the most demanding of the trainee and require some of the most complex equipment for simulation.

### 6.2.2 Feedback

- in general Zeitgeist has been that feedback or knowledge of results facilitates training. (see Smode, 1958) While this is true in the general case there are cautions which should be observed when applying the feedback principle to the particular case or when carrying out research with particular tasks. For example, Briggs (1962) points to the interactive effect of type of augmented feedback (positive or negative), complexity of the feedback criteria and level of training. He draws attention also to the importance of the feedback withdrawal schedule. Ward and Senders (1966) suggest that adding an element to the task such as a feedback method has a degree of workload associated with it and may interfere with carrying out the primary tasks due to the time sharing requirements.

The work of Feuerzeig (1971) in providing instructional monitoring is believed to be a method of feedback which should prove highly beneficial in Undergraduate Pilot Training but must be investigated as to the interference effects and the feedback withdrawal schedule.

Feuerzeig provided the trainee with computer generated diagnostic information, instructional suggestions and a two-dimensional dynamic display of the progress through a task such as a holding pattern. His results suggest that such an approach to feedback to the UPT trainee, particularly for instrument flight training, should be investigated.

### 6.2.3 Sequencing of Training Tasks

While sequencing of training tasks was listed as being one of the top priority items by the Training Problem Panel, it is suggested that the solution to this problem is more properly carried out using the ISD task analysis approach suggested in Manual 50-2. How best to teach each of the separate tasks may be approached through research in training methodology such as those of cognitive pre-training and feedback. It is recommended that the proper sequencing of these tasks, however, may more properly be done through synthesizing the tasks into an overall curriculum by the use of ISD procedures. The comparative test of two optimized sequences may be carried out as a final test using the ASUPT as the criterion device within which all training is given and final training is tested. This final comparative experiment should be undertaken after thorough analyses of the tasks required of the pilot and should properly include a synthesis of the tasks of the total curriculum based upon the analysis carried out by Meyer et al. (1974).

### 6.2.4 Contextual Training

The arguments for investigation of contextual training are identical to those just presented for sequencing of the training tasks. The context within which certain tasks are to be trained should be established and synthesized by task analysis prior to any experimental investigations. Comparative studies of two or three of the candidates for "contextual" training should then be investigated in ASUPT using it as both the training and the criterion device.

### 6.2.5 Individualized Instruction

Individualized instruction is such a broad and diversified area that it is not possible to describe research relevant to it in this report. The research outlined with respect to training methodologies such as feedback and cognitive training will provide information as to instructional strategies which may go into an individualized instructional system. It is recommended that the individual characteristics such as biographical data and subject source, i.e., Air Force Academy, ROTA and so forth be maintained on all trainees used as subject in the experiment. The predictive validity of research findings will rest in large part on information about present and future trainee populations. Thus, a data base may be developed for making management decisions about individualized instructional programs which may be automated to assign instructional strategies, incentives and guide the trainees' progress as a function of his rate of skill attainment, biographical background and other individual characteristics upon which he may have been selected. The research being carried out by Human Resources Laboratory, Technical Training Division, with respect to individualized training will provide useful data for management decisions about individualized instruction in flying training and should form a part of the data base.

# REFERENCES

1. Bahrick, H. P. and Noble, M. C., Motor Behavior in Experimental Methods and Instrumentation in Psychology, J. B. Sidowski (Ed)., New York: McGraw-Hill.

2. Bell, F. E., III, Advanced simulation in undergraduate pilot training (ASUPT), Technical Fact Sheet, AFHRL/FT TN 73-01, Air Force Human Resources Laboratory, Flying Training Division, Williams AFB, Arizona, May, 1974.

3. Briggs, G. E., Research on augmented feedback and the acquisition and transfer of skill, Technical Report: NAVTRADEVCEN 836-3, U. S. Naval Training Device Center, Port Washington, N. Y., September 1962.

4. Bynum, J. A., Matheny, W. G., Flexman, J. E. and Wilson, R. K., Test of a model of visual spatial discrimination and its application to helicopter control, LSI-TR-73-1, Annual Summary Report, U. S. Army Medical Research and Development Command, Washington, D. C., November, 1973.

5. Demaree, R. G., Norman, D. A. and Matheny, W. G., An experimental program for relating transfer of training to pilot performance and degree of simulation, Technical Report NAVTRADEVCEN 1388-1, U. S. Naval Training Device Center, Port Washington, New York, July, 1964.

6. Feurzeig, W., Automated instructional monitors for complex operational tasks, Report No. 2272, Bolt, Beranek and Newman, Inc., Cambridge, Mass., October, 1971.

7. Flexman, R. E., Matheny, W. G. and Brown, E. L., Evaluation of the school and special methods of instruction, Aeronautics Bulletin Number Eight, University of Illinois, Urbana, Illinois., 1950.

8. Flexman, R. E., Townsend, J. E. and Ornstein, G. N., Evaluation of a contact flight simulator when used in an Air Force primary pilot training program: Part I. Over-all effectiveness, Technical Report AFPTRC-TR-54-58, 1954.

9. Gagne, R. M., Foster, H. and Crowley, M. E., The measurement of transfer of training, Psychology Bulletin, 1948, 45, 97-130.

10. Hagin, W. V. and Smith, J. F., Advanced simulation in undergradupate pilot training (ASUPT) facility utilization plan, Technical Report AFHRL-TR-74-43, Air Force Human Resources Laboratory, Flying Training Division, Williams AFB, Arizona, June, 1974. (AD-786 411)

11. Hasbrook, H. and Young, P. E., Peripheral Vision cues: Their effect on pilot performance during instrument landing approaches and recoveries from unusual attitudes, Report No. AM 68-12, Federal Aviation Administration, Office of Aviation Medicine, Civil Aeromedical Institute, May, 1968.

12. Hill, J. W. and Goebel, R. A., Development of automated GAT-1 performance measures, AFHRL-TR-71-18, Air Force Human Resources Laboratory, Flying Training Division, May 1971. (AD-732 616)

13. Matheny, W. G., The effective time constant - a new technique for adaptive training, Human Factors, 1969, 11 (6), 557-560.

14. Matheny, W. G. and Norman, D. A., The effective time constant in tracking behavior, Technical Report: NAVTRADEVCEN 67-C-0034-3, Naval Training Device Center, Orlando, Florida, August 1968.

15. Matheny, W. G., Lowes, A. L., and Bynum, J. A., An experimental investigation of the role of motion in ground-based trainers, Technical Report: NAVTRAEQUIPCEN-71-C-0075-1, Naval Training Equipment Center, Orlando, Florida, 1974.

16. Meyer, R. P., Laveson, J. I., Weissman, N. S. and Eddowes, E. E., Behavioral taxonomy of Undergraduate Pilot Training tasks and skills: Surface task analysis, taxonomy structure, classification rules and validation plans, AFHRL-TR-74-33 (II), Air Force Human Resources Laboratory, Flying Training Division, Williams AFB, Arizona, July, 1974. (AD-A000 053)

17. Norman, D. A., Adaptive training of manual control: Relation of adaptive scheme parameters to task parameter, Technical Report: NAVTRAEQUIPCEN 70-C-0218-1, Naval Training Equipment Center, Orlando, Florida, 1973.

18. Payne, T. A., Improving landing performance using a contact landing trainer, Technical Report SPECDEVCEN 71-16-11, Special Devices Center, Port Washington, New York, March, 1954, (AD-121200).

19. Smith, J. F., Application of the advanced simulation in undergraduate training (ASUPT) research facility to pilot training problems, Proceedings of the Third Annual Psychology in the Air Force Symposium, USAFA Department of Behavioral and Life Sciences, April, 1972.

20. Thielges, J. R. and Matheny, W. G., Analysis of visual discrimination in helicopter control, Technical Report 71-13, Human Resources Research Organization, June, 1971.

21. Waag, W. L., Summary of HRL/FT in-house effort on proficiency measurement, Air Force Human Resources Laboratory, Flying Training Division, Personal Communication, 1974.

22. Ward, J. L. and Senders, J. W., Methodological studies of tracking behavior: The effect of various supplemental information feedbacks, Report No. 1458, Bolt, Beranek and Newman, Inc., Cambridge, Mass., May, 1966.

23. Woodruff, R.R., Smith, J.F., & Morris, R.A. Use of the T-4G simulator in USAF undergraduate pilot training (UPT), Phase I. AFHRL-TR-74-61, AD-786 413. Williams AFB, Ariz.: Flying Training Division, Air Force Human Resources Laboratory, July 1974.

## APPENDIX A

### Letter of Invitation and Instructions to Research Problems Panel

Life Sciences, Inc., under Contract F41609-73-C-0038 with the United States Air Force, is carrying out an investigation the purpose of which is to produce a Handbook of experiments dealing with the design and utilization of training simulators. This document will outline the more important experiments necessary of being carried out in order to answer critical questions regarding simulator hardware design and methods of simulator utilization. The research to be recommended in this Handbook is to be carried out using the Advanced Simulator for Undergraduate Pilot Training (ASUPT) or other research facilities available to the Air Force Human Research Laboratory/Flight Training at Williams Air Force Base.

It is expected that the problems to be attacked will be those important to a wide range of training situations in which the trainee acquires cognitive and psychomotor skills in learning to control a man-machine system. However, our emphasis is upon the research through use of the ground-based trainer and training technology in beginning pilot training.

In order to make the Handbook of most value to Air Force research and to ensure the most generality across a wide range of beginning pilot training programs, we are attempting to involve as many individuals with experience and knowledge in the problems of beginning training as possible. This involvement takes the form of asking the individuals to present their views as to the most critical training problems to be attacked using a facility such as ASUPT and the other HRL/FT devices. Therefore, we are attempting to obtain the considered judgments of a group of experts in the field as to the important training problems. After these have been assembled they will be listed and submitted back to the group for priority judgments or order in which they should be taken up in a research program.

I would appreciate very much your becoming a member of this group. Your participation as a member would be most valuable.

I should point out that other equipment available for research on training problems consists of a T-4G simulator which is a modification of the ME-I built by Link. Its main features are a mostion base and a visual system. The motion system provides three degrees of motion in pitch, bank and heave. The visual display provides a visual image of 44° by 28° in full color through use of color film and 35 mm slides. This visual system is known as the Electronic Perspective Transformation (EPT) system and presents an approach, landing and take-off sequence filmed at Williams Air Force Base.

Other equipment includes three T-40 trainers which were designed to train flight personnel in the typical twin engine jet aircraft. This trainer consists of a cockpit mounted on a two degree of freedom motion system and an instructor's station. The motion system provides motion in the pitch and roll axes. However, the pitch motion also provides vertical translation at the pilot's center of gravity to simulate heave motion. The trainer may be considered as an instrument flight trainer and useful in research on the problems of instrument flight, engine systems, navigation, radio, communications and so forth for this type of aircraft.

A third trainer is termed the simplified Formation Flight Trainer (FFT). This device is configured to train the student in formation flying of the T-38 aircraft. The student "flys" a television camera which views a model of a T-38 training aircraft. The image of this model is projected on a wide angle screen at the student's station. All basic formation tasks from join up to position keeping and in cross-under can be accomplished in the trainer.

I hope that you will be able to help as a member of our panel of experts and can send me your thoughts on what you regard to be the critical research issue in simulator design and utilization at an early date.

Best regards,

W. G. Matheny
President & Technical Director

# APPENDIX B

Life Sciences, Inc.
Contract F41609-73-C-0038

## Training Problems List

### Visual Simulation Requirements

The visual system in aircraft simulators presents the real world visual scene outside the aircraft to the trainee. Major problems in this area are:

- Field of View - The solid visual angle to be covered by the display. Measured from a forward line-of-regard, the vertical and horizontal visual angles to be covered by the display.
- Content of the Display - Objects, points, lines and so forth in the display as sources of information for the trainee in carrying out his aircraft control tasks.
- Quality of the Display - Aspects of the display such as brightness, resolution, sharpness, contrast, and distortion or aberrations of the displayed image which have to do with its legibility.
- Color - The chromaticity of the display, i.e., whether the visual display is achromatic or contains an approximation to real world color.
- Depth of Field - The image being displayed to the trainee is collimated and thus appear at virtual infinity or appear as a flat plane projection.

### Motion Cue Simulation

This area of research may be subdivided into what may be termed the onset or true motion cues and their washout and those cues which are sustained by means of pressures on the trainee's body. The latter may be implemented by pneumatically driven elements in the simulator seat (G-Seat) and through the gravitational alingment cue provided by tilting the motion platform. Motion cues may be provided by the movement of the simulator motion platform and possibly the actuation of the pneumatically driven elements in the G-Seat. The individual research items have been broken out as follows:

- Contribution of the individual or combined degrees of freedom of motion of the platform to training of the undergraduate pilot trainee.

- Contribution of the individual or combined motions of the degrees of freedom of motion of the platform to the proficiency measurement of the trainee, e.g., periodic or final checks.

- Contribution of the gravity alignment cue to training. This cue comes from tilting the platform such that normal gravity is used as a substitute for the acceleration when the aircraft is accelerating or decelerating, e.g., during landings.

- Determination of the degree to which the seat pan and belt pneumatically driven elements (G-Seat) may provide the motion cues available to the trainee during various training tasks and maneuvers.

- Determination of the contribution to training of the sustained pressures provided by the pneumatically driven element of the student's seat.

- Determination of the optimum frequency response in pitch, roll and yaw of the platform for training cost effectiveness, i.e., what fidelity of motion is optimum for training.

- Determination of the optimum program for introduction and washout of linear movement of the motion platform and G-Seat for training effectiveness.

### Motion-Vision Interaction

This area of research is concerned with determining the combined effects upon training effectiveness of the vision and motion characteristics of the device.

### Feedback

This area is concerned with the provision of feedback (knowledge of results) to the student about his performance. Usually feedback is given relevant to some criterion or standard. This area can be divided into categories as follows:

- Freeze Capability - Refers to the most effective use of the simulator "freeze" capability in providing feedback.

- Sensory Channel - Refers to the determination of the most appropriate sensory channel for use in providing feedback or knowledge of results to the student.

- Instructor Provided - Refers to the determination of what information should be given to the student by the instructor as to the quality of his performance based upon information he obtains either from his observations of the student's activities, panel instruments, contact scene or, in the case of the simulator, specific performance measures of both criterion and diagnostic nature.

- Frequency - Refers to the frequency with which feedback should be given to the student, i.e., continuous or at discrete intervals during his practice of the task.

- Time Delay - Refers to the time interval between the performance of the task and the presentation of information relative to the adequacy or quality of the performance, i.e., whether feedback is immediate or delayed.

- Visual Modeling - Refers to the process of exhibiting to the student on a visual display his progress through a maneuver as a developing two-dimensional spatial pattern on a visual display. For example, while the student is performing a holding pattern using information derived from the instruments on the aircraft panel a CRT display may graph for him his ground path relative to the desired holding pattern. This information may be withdrawn as trainee learning progresses.

- Self-Confrontation - Refers to the playback of a trainee's performance during a practice trial through activation of the instruments and controls of the simulator. Playback may be either in slow, real or fast time.

## Disorientation Training

This category is concerned with the research into training to recognize and cope with disorientation during flight. It investigates the requirements for a simulator to induce disorientation and the methods and techniques for training in recognizing and coping with the problem.

## Auditory Cue Simulation

This area of research is concerned with the auditory spectra emanating from the aircraft which may be important in training in several different ways as follows:

- As an information source which the student uses in directing his control movements.

- As a means of adding realism to the training situation.

- As noise which interferes with obtaining information or which may otherwise be detrimental to performance.

## Kinesthetic Cue (Control Feel) Simulation

This area of research deals with the investigation of the degree to which the control forces and displacements in the aircraft being simulated should be represented in the simulator.

## Contextual Training

This area of concern is with training taking place within the context of operational tasks and applications. For example, basic instrument maneuvers such as 30° bank turns could be taught in the context of an overall maneuver such as an instrument approach. An experimental question in this area might then be, should tasks such as 30° bank turns be practiced separately and uniquely or within the context of a broader maneuver?

## Performance Measurement

Within this category there are five identifiable, independent subcategories as follows.

- Check-ride Performance - Extent to which check or criterion rides in the simulator may be substituted for those in the aircraft.
- Diagnostic Measures - Measures of specific items at a particular time during a practice session or learning process which are designed to identify and isolate specific sources of difficulty being experienced by the trainee in his acquisition of the criterion skills or knowledge.
- Control Output Measures - Identification of the parameters to be sampled and recorded, e.g., lateral stick input, and the methods for summarizing or transforming them into the most meaningful and valid form, e.g., spectral density function or frequency analyses.
- System Output Measures - Identification of those parameters to be sampled and recorded by maneuver or task, e.g., altitude or airspeed, and the methods for summarizing them into the most meaningful and valid form, e.g., integrated absolute error, RMS, etc.
- Observer Records of Performance - Investigation of the methods and techniques whereby the instructor pilot or other observer may record performance through watching the standard instruments of the aircraft panel, the contact world scene and the actions of the trainee.
- Observer Opinion Data - Investigation of the methods and techniques whereby an observer such as an instructor pilot,

test pilot, design engineer or behavioral scientist may record or express his judgments or opinions in a useful and reliable manner.

- Determination of the relationship between specific and detailed diagnostic and criterion measures obtainable in the simulator and those measures possible of being obtained by the instructor pilot observing the trainee performance in the aircraft.

## Instructional Aids

This area of research is concerned with the methods, procedures and part-task devices which may be used in connection with a simulator and within a training system to bring about more effective training. The list of items which may be broken out under this category are as follows:

- Maneuver Demonstration - Refers to the capability of the device for "playing through" the maneuver in automated mode for the purpose of demonstrating it to the student.

- Instructional Cues - In this item of research use is made of the instructional cues derived from task analyses in that the instructional cues for each task or maneuver are singled out and made explicit for the trainee. Instructional cues are defined as the stimuli which provide the information, often in the form of a rule or a set of procedures, which enables the learner to perform the behavior described in a performance objective. It is the minimal informational stimulus, either audible, visual or tactual, which must be supplied to the learner in order to enable him to make the desired response. The emphasis in this area of research would be the pointing out or making explicit to the learner what instructional cues are involved in performing the task. This may be carried out through use of the visual and/or auditory display capabilities of the ASUPT or use of other less complex audio and/or video devices.

- Part-Task Trainers - Research using much less complex devices than the ASUPT to train in parts or aspects of a task prior to ASUPT training. Such devices might include full scale panel illustrations or pictures, mock-ups, procedures, trainers and audio-visual devices for training in procedural, perceptual and cognitive type tasks.

- Prompting and Cueing - Prompts are signals which indicate that the time has come for a specific action to occur and directs the student to perform that particular action. Cueing is similar to prompting but usually refers to a simple signal that indicates time to act. Thus, a cue is less directive than a prompt.

## Aircraft Dynamics Simulation

This area of research deals with the degree to which the equations describing the motions of the simulated aircraft should be represented and implemented in the simulator. It is directed essentially toward the degree to which these equations might be simplified in their implementation in the simulator with possible reduction in required computer speed and/or capacity.

## Peer Training

Research in which the trainee's peers may observe and work with him while he practices or engages in the solution of problems. This category may be subdivided as follows:

- Instructional Assist - In which the fellow trainee engages in helping the trainee solve problems or improve his skills through discussion, suggestion and critique of his performance.
- Dynamic Observer - In which the fellow trainee acts as an observer and notes the performance of the trainee being observed, the types of errors which develop, and can mentally rehearse his own techniques and approach to solving the problem or acquiring the skill.

## Instructor's Role and Training

This area of research is concerned with developing information which may be used to make the instructor more effective in his guidance and management of the student's progress through the training curriculum. It may be subdivided into the following categories:

- Performance Evaluation - This area includes research in the training of the instructor in the evaluation of the performance of the trainee in the simulator and in the aircraft and the relationship between the performance measures obtained in each of these training situations. A greater array of performance evaluation means is available to the instructor in the simulator than in the aircraft. Instructor training in the use of diagnostic and criterion proficiency measurements in the simulator is the concern of this research area. Of particular concern is the interpretation and translation of the more detailed measures taken in the simulator into instructional guidance and performance evaluation in the aircraft.
- Use of the diagnostic information provided by the simulator performance measures for either extemporaneous or standardized instructions and guidance to the trainee.

- Degree of Instructor Participation - This research item refers to the degree to which the instructor actively participates in the ongoing practice of the trainee. On the one hand the instructor may demonstrate the task, talk the student through maneuvers and provide evaluative and directive information throughout the course of the student's practice. On the other, he may adopt a passive role in which he provides information only when questioned by the trainee and injects himself into the training practice only to assure safety.

- Instructor Motivation - Investigation of the incentives and awards which may be used to increase instructor interest and enthusiasm.

- Instructor Standardization - Research concerned with training and measuring the instructor's ability such that he maintains his effectiveness at a defined and established level.

- Degree of Instructor Task Automation - This item refers to the analysis of the instructor's task and the allocation of certain of these to automatic execution by the training simulator. The types of functions and tasks that fall within this category are briefings, demonstrations, performance evaluation and assignment of training tasks.

- Instructor as Training Manager - Refers to the instructor's control of the progression of the student through the syllabus based upon student performance relative to specified criteria using specific task descriptions and criteria and having available to him detailed knowledge of the student's progress through diagnostic as well as criterion performance measurement.

- Instructor Station and Role in UPT Simulation - Refers to such questions as whether the instructor should be located in or out of the cockpit and the optimum design of the instructor's console.

## Relationship of Trainee Traits and Methods of Instruction

This area of research is concerned with the investigation of relationships between methods of presenting the training materials and certain measurable traits of the individual. For example, measurable traits such as visual field dependency, manifest anxiety or perceptual and cognitive style may be hypothesized to be related to the appropriate method or mode of instruction to be used for a given trainee.

## Cognitive Pre-Training

This area refers to extensive briefing or complete understanding of the perceptions and actions required for completing a task before it is attempted in the simulator or the aircraft.

## Sequencing of Training Tasks, Maneuvers and Phases

This area of research is concerned with the ordering of the tasks, maneuvers and phases such that optimum transfer from fundamental skills and knowledges to tasks of greater difficulty is obtained and results in the most efficient progression through the syllabus. Specific research questions may range from whether instrument flight training should precede or follow contact flight training to investigations which seek to determine the hierarchy of skills in the optimum order and methods of teaching these basic skills.

## Trainee Motivation

This area of research involves investigation of the role which incentives may play in bringing about more effective training. These may involve competion among trainees or other incentives and awards for accomplishment.

## Extension of the Training Syllabus

This area is concerned with determining the emphasis to be placed upon training tasks and maneuvers which are avoided in the aircraft for reasons of safety, and those which require controlling the aircraft to the limits of its performance and structural integrity, e.g., control at the critical airspeed limits.

## Adaptive Training

In the simulated environment, UPT may be adapted in various ways. Under either automated or manual control, the actual task, the syllabus, and/or simulator characteristics can be modified. The specific items in this area are:

- Individualized Instruction - Determination and description of the specific tasks to be taken up in the syllabus, specification of criterion performance either normative or administrative, and progression of the student through the syllabus on a performance to criterion basis with provisions for branching back for rehearsal of tasks.

- Machine Adaptive Training - Adjustment of the characteristics of the training device or media or task such that the trainee progresses to criterion performance at his own individual pace based upon measurement of his progress. Adjustment of the training situation is customarily such that the trainee's task is easy during his initial practice trials and is adjusted to become difficult based upon his progress until he reaches criterion performance.

## APPENDIX C

Life Sciences, Inc.
Contract F41609-73-C-0038

### Assignment of Priorities to Training Problems

The attached list describes areas of research which have been identified as those which are pressing in terms of their importance for making pilot training more effective. Research results providing definitive information in these areas would be highly useful in making decisions as to the way training should be conducted and the type of training equipment that should be used.

What is needed now is an ordering of the listed items in terms of their importance to increasing the effectiveness of beginning or undergraduate pilot training. That particular item which the rater feels should be taken up first in an undergraduate pilot training research program should appear at the top of the list. The basis for assigning priorities should be the importance of the research item for its potential for increasing training effectiveness. Increasing training effectiveness is defined as bringing the student to criterion proficiency in less training time at less training cost.

The question posed to the rater is - what is the particular order in which the items of research should be accomplished in order to provide the most useful information to administrators in making training program decisions. It is hoped that a reasonably concise and unambigious definition of each of the research areas has been given so that they may be reviewed and priorities assigned.

Each of the items has been listed separately on a 3 x 5 card so that they may be sorted and arranged in order of priority. As you receive them the cards will be in the same order as the items in the attached list. The procedure for sorting is to select a given card and place it face up before you. Each of the other items (cards) is examined and a judgment made as to whether it is of greater or lesser priority than the first chosen (reference) card. Any item which is judged to be of higher priority than the reference card is placed to the right of that card while those judged to be of lesser priority are placed to the left. At the conclusion of this sort the right hand stack of cards is taken up and sorted in precisely the same manner. That is, a reference card is chosen and placed face up before the rater. The remaining cards in the stack are then sorted into two piles, one on either side of the reference card designating either higher priority or lower priority than the reference card. This procedure is repeated for all stacks until no one has more than three or four item cards in it. These three or four may then be ranked from high to low in priority. The total stack of cards is then reassembled from greatest to least priority. If it is convenient the items should be typed into a list in the priority order shown by the cards. If this is not convenient, the prioritized card stack should be secured firmly and returned to Life Sciences in this form. It is preferred, both for convenience in mailing and for insuring that the items will not be gotten out of order, that the typed list be made.

# APPENDIX D

*Ranking of Training Problems Based*
Upon Median Rank (10 Raters)[1]

| | ITEM | MEDIAN | Q |
|---|---|---|---|
| 1. | Content of the Visual Display | 6.0 | 10.75 |
| 2. | Motion-Vision Interaction | 11.0 | 11.50 |
| 3. | Quality of the Visual Display | 12.5 | 19.75 |
| 4. | Performance Measurement-System Output Measures | 12.5 | 12.75 |
| 5. | Sequencing of Training Tasks | 14.0 | 11.00 |
| 6. | Contribution of the Individual or combined Degrees of Freedom of Platform Motion to Training | 14.0 | 11.75 |
| 7. | Instructor Training - Performance Evaluation | 14.5 | 11.00 |
| 8. | Cognitive Pre-Training | 15.0 | 9.75 |
| 9. | Performance Measurement - Diagnostic Measures | 18.0 | 10.00 |
| 10. | Adaptive Training - Individualized Instruction | 18.0 | 7.50 |
| 11. | Feedback - Self-Confrontation | 20.0 | 14.25 |
| 12. | Feedback - Visual Modeling | 20.0 | 8.00 |
| 13. | Instructor Training - Use of Diagnostic Information for Student Guidance | 21.0 | 12.00 |
| 14. | Feedback - Sensory Channel | 21.5 | 18.75 |
| 15. | Instructional Aids - Instructional Cues | 21.5 | 8.50 |
| 16. | Contextual Training | 22.0 | 9.00 |
| 17. | Contribution of the Individual or Combined Degrees of Freedom of Platform Motion to Proficiency Measurement | 24.0 | 17.50 |
| 18. | Instructor Training - Degree of Instructor Participation | 24.5 | 18.00 |
| 19. | Feedback - Instructor Provided | 24.5 | 18.00 |
| 20. | Field of View | 25.0 | 16.75 |
| 21. | Adaptive Training - Machine | 25.5 | 10.75 |
| 22. | Determination of the Optimum Fidelity of Response in Pitch, Roll and Yaw of the Motion Platform | 25.5 | 16.00 |
| 23. | Instructor Motivation | 26.0 | 23.75 |
| 24. | Performance Measurement - Relationship | 27.5 | 9.50 |
| 25. | Determination of the Degree to Which G-Seat May Provide Motion Cues | 27.5 | 7.75 |
| 26. | Feedback - Frequency | 28.5 | 12.75 |
| 27. | Performance Measurement - Observer Records of Performance | 28.5 | 13.25 |

Ranking of Training Problems Based
Upon Median Rank (Cont'd)

| | ITEM | MEDIAN | Q |
|---|---|---|---|
| 28. | Determination of the Optimum Program for Linear Movement of the Motion Platform | 29.0 | 13.75 |
| 29. | Determination of the Importance of the Auditory Spectra as an Information Source | 29.0 | 16.00 |
| 30. | Instructor Role as Training Manager | 29.5 | 16.25 |
| 31. | Peer Training - Instructional Assist | 29.5 | 11.75 |
| 32. | Performance Measurement - Control Output Measures | 30.0 | 14.25 |
| 33. | Instructional Aids - Part-Task Trainers | 31.0 | 14.0 |
| 34. | Depth of Field of View in the Visual Display | 31.5 | 18.50 |
| 35. | Instructional Aids - Prompting and Cueing | 32.0 | 12.25 |
| 36. | Instructor Standardization | 32.0 | 16.25 |
| 37. | Performance Measurement - Checkride performance | 32.5 | 10.00 |
| 38. | Determination of the Contributions to Training of the Sustained Pressures Provided by the G-Seat | 33.0 | 17.50 |
| 39. | Degree to Which the Control Forces and Displacements Should be Represented in the Simulator | 33.5 | 11.50 |
| 40. | Relationship of Trainee Traits and Methods of Instruction | 33.5 | 20.75 |
| 41. | Instructor Training - Degree of Instructor Task Automation | 34.0 | 19.50 |
| 42. | Peer Training - Dynamic Observer | 34.0 | 13.25 |
| 43. | Instructional Aids - Maneuver Demonstration | 35.0 | 15.50 |
| 44. | Extension of the Training Syllabus | 35.0 | 14.75 |
| 45. | Contribution of the Gravity Alignment Cue to Training | 35.0 | 16.25 |
| 46. | Disorientation Training | 35.5 | 11.25 |
| 47. | Feedback - Time Delay | 36.0 | 10.00 |
| 48. | Trainee Motivation | 36.5 | 20.50 |
| 49. | Performance Measurement - Observer Opinion Data | 38.0 | 8.00 |
| 50. | Determination of the Importance of the Auditory Spectra as a Means of Adding Realism to the Training Situation | 40.0 | 5.50 |
| 51. | Determination of the Importance of the Auditory Spectra as Interference or Noise | 44.0 | 10.75 |
| 52. | Aircraft Dynamics Simulation | 45.0 | 18.75 |

## Ranking of Training Problems Based Upon Median Rank (Cont'd)

| | ITEM | MEDIAN | Q |
|---|---|---|---|
| 53. | Feedback-Simulator Freeze Capability | 47.0 | 7.00 |
| 54. | Color in the Visual Display | 47.5 | 10.25 |
| 55. | Instructor Station - Location and Design | 48.0 | 7.25 |

Note I.

In this table the median refers to the mid-point in the distribution of ratings given by the judges. It is that rating value at which one-half or 50% of the judges ratings of the particular item were greater than the value and one-half of them were lower. The Q value in the table is a measure of the variability of the judges' ratings and is called the semi-interquartile range. The formula for cue is $Q = Q_3 - Q_1$. $Q_1$ is the point one-quarter through the distribution of ratings, i.e., the point at which 75% of the ratings are above this value and 25% are below. $Q_3$ is the point three-quarters of the way through the distribution. Thus, the difference between $Q_3$ and $Q_1$ divided by two is a measure of the spread or variability of the judges' ratings.

# APPENDIX E

## Scenario for Flights of Instrumented T-37 Aircraft

### Sortie No. 1

1. Record runway barometric pressure and temperature, date, time.

2. Take-off.

3. Turn on recorder.

4. Gear-up - record, (1) event no., (2) fuel quantity, (3) turbulence level, (4) "climb".

5. Climb to 15,000 feet at a constant 180 KIAS. Perform 4 - 2 minute trials during climb. Trim before each trial as necessary.

6. Fly to area where maneuvers can be flown.

7. Update event mark - record, (1) event no., (2) fuel quantity, (3) turbulence level, (4) "descent".

8. Descend at a constant airspeed of 200 KIAS to 2,000 feet. Perform 4 - 2 minute trials during descent. Trim before each trial as necessary.

9. Trim to 200 KIAS, straight and level, 2,000 feet.

10. Record (1) event no., (2) fuel quantity, (3) turbulence level, (4) trial order A.

11. Fly 2 minute trials in order A. Trim before each trial as necessary.

12. Record (1) event no., (2) fuel quantity, (3) turbulence level, (4) "straight and level to base".

13. Return to base at 2,000 feet. Perform 2 minute trials straight and level during return. Trim before each trial as necessary.

## Sortie No. 2

1. Record runway barometric pressure and temperature, date, time.

2. Take-off.

3. Turn on recorder.

4. Gear-up - record, (1) event no., (2) fuel quantity, (3) turbulence level, (4) "climb".

5. Climb to 15,000 feet at a constant 180 KIAS. Perform 4 - 2 minute trials during climb. Trim before each trial as necessary.

6. Fly to area where maneuvers can be flown.

7. Record, (1) event no., (2) fuel quantity, (3) turbulence level, (4) "descent".

8. Descend at a constant airspeed of 200 KIAS to 2,000 feet. Perform 4 - 2 minute trials during descent. Trim before each trial as necessary.

9. Trim to 200 KIAS, straight and level, 2,000 feet above ground.

10. Record (1) event no., (2) fuel quantity, (3) turbulence level, (4) trial order B.

11. Fly 2 minute trials in order B. Trim before each trial as necessary.

12. Record (1) event no., (2) fuel quantity, (3) turbulence level, (4) "straight and level to base".

13. Return to base at 2,000 feet. Perform 3 - 2 minute trials straight and level during return. Trim before each trial as necessary.

### Sorties 3 & 4

Repeat Sorties No. 1 and 2 except perform straight and level and 30° bank turns at 100 KIAS.

### Sorties 5 & 6

Repeat Sorties No. 1 and 2 except perform straight and level and 30° bank turns under contact conditions.

### Sorties 7 & 8

Repeat Sorties No. 1 and 2 except perform straight and level and 30° bank turns are at 100 KIAS and under contact conditions.

## APPENDIX F

## Eye-movement Recordings and Data Analysis

It is recommended that the NAC Eye Mark Recorder is to be used as a method for gathering data for the identification of the objects comprising the content of the visual display which can be used as referents by the pilot in control of his aircraft. The NAC Eye Mark Recorder provides a record of a primary field of view 60° in azimuth of the scene directly forward of the pilot's head position and an indication on this field of view of the pilot's fixation point within the scene. Specifically, this recorder is an optical device which focuses an illuminated reticle reflected by the movement of the eyeball so that it always coincides with the visual line-of-regard. This is superimposed on the primary image and may be recorded on 16mm film or video tape. The video tape recording method is recommended because of its capability for instant replay.

The general approach recommended for the collection of these data is to require instructor pilots to fly representative undergraduate pilot training maneuvers while their eye movements are recorded. The specific maneuvers recommended to be flown are (a) straight and level, (b) steep turn, (c) complete (deep) stall, (d) lazy eights, (e) a shallow turn, (f) pattern, approach and landing, and (g) formation flight.

Instructor pilot subjects will be selected who are current in the maneuvers to be accomplished during data collection. These pilots will be briefed on the general characteristics of the eye mark recording equipment and such safety procedures as are required. This briefing will include information as to the purpose of the maneuver and data collection procedure. The pilots will be informed as to why they are being monitored and that at the conclusion of a flight they will be asked to review the recordings of their eye movements and to relate what elements of the visual scene they were using as they piloted their aircraft.

An important phase of this investigation is the post flight review by the pilot of his eye-movement recordings. It is necessary, on a moment-by-moment basis, for the subject pilot to identify the particular element in the contact world scene which he is using to provide him with information for control of specific dimensions of movement of his aircraft. It is also necessary that he identify any relationships either static or dynamic between the external world referents and those fixed to his aircraft. These referent points will serve to identify objects, points, lines, features or characteristics which may then be generated in the contact real-world scene provided by the simulator. These identified referents will provide the basis for investigations as to the content objects and their location in subsequent research investigations.

It is also hypothesized that it is a requirement of the pilot trainee to learn to identify and extract the pertinent referents from visual "noise" in the contact world scene. This noise is comprised of other objects or conditions which serve to obscure the referent and interfere with fine discriminations of its relationship to other referents. During the post flight interview the pilot must be asked whether he can identify such condition in the videotape he reviews. They may be such factors as haze, atmospheric attenuation, low contrast, or any other which tended to interfere with or degrade his visual perceptions.

Of particular interest in the post-flight interview is information relevant to the peripheral cues observed and used by the pilots during the flight. The long standing belief in the importance of peripheral cues (Hasbrook & Young, 1968) has been recently reinforced by data collected by Life Sciences, Inc. in which pilots eye-movement records were taken while hovering the helicopter. These records show that a pilot could fixate steadily on a given point on the ground plane for a long period of time while controlling all six dimensions of movement of his aircraft indicating great reliance on peripheral visual information.

Although the NAC Eye Mark Recorder is equipped with a 60° field of view lens the peripheral vision of the human operator extends beyond that field and it is quite probable that information is available and utilized by the pilot which is not recorded. The post-flight review of the recordings and the interviews should cover this possibility, i.e., the pilot should attempt to recall and elaborate upon any peripheral cues which are not visible in recordings at any point he feels necessary.

Although the line-of-regard of the pilot can be established with the Eye Mark Recorder this does not establish the fact of the object or area on which the eye is focused. That is to say, that the line-of-regard reticle of the recorder resting upon an object does not necessarily mean that the eye is focused upon that object, although it is highly probable that it is. The pilot, therefore, must be able to explain precisely what object or point he was focused upon during the portion of the maneuver which is visible on the video tape. The pilot may provide narrative information on a voice tract of the video tape during data collection. This narrative is not deemed critcally necessary but could prove helpful. If there is any indication that such a narration is interferring with the pilots normal flying of the maneuver it should be discontinued.

Although it is preferable that a given maneuver be accomplished in "discrete" fashion with immediate return to the flight line for playback and interview, the data collection sequence is open to variations because of the practicalities of flight data collection. For example, data might be collected on taxi and take-off, climbout, and immediate approach and landing with return to the flight line and playback and interview covering this sequence. It is recommended, however, that to the maximum extent possible, an extended sequence of maneuvers not be accomplished since it would require a greater amount of recall by the pilot and certain factors may be forgotten before the interview session.

Documentation of eye point data in the total field of view will be of direct assistance in establishing the visual environment of the pilot and can be utilized in other programs. For example, the data could be used by instructor pilots for directing the student's attention to particular areas of the visual field during training. However, first and primary use of the records and the interview data is in generating hypotheses as to the visual image content and fields of view to be tested in ASUPT.

The outline of the procedure for carrying out the eye-movement data collection and analysis is as follows:

*o Purchase NAC Eye Mark Recorder and modify for helmet mounting

*o Preliminary try-out of equipment and procedures with HRL/FT personnel

o Selection of instructor pilot subjects

o General orientation and safety briefing

o Selection and data collection on maneuver

o Playback and interview concerning maneuver

o Analysis tc determine field of view

o Formulation of hypotheses for test

*Accomplished as of this date

At the time of the writing of this report the eye-movement recording program is going ahead at HRL/FT. As indicated in the list of procedures to be accomplished the NAC Eye Mark Recorder was obtained and modified for helmet mount. Preliminary data collection to try out both the Eye Mark Recorder and the video tape equipment has been accomplished using ground vehicles. The means for mounting and operating the eye mark equipment and the recorder in the TF37 aircraft have been specified.

## APPENDIX G

## Functional Description of AVIT Device

A schematic drawing of the existing AVIT is given in Figure 1.

The stimulus devices to which student responds are:

1. An 18 x 11 inch rear-projection screen on which photos of the basic flight instrument panel of the T-37, or other photographic, written, or diagrammatic material, as appropriate, may be presented;

2. A head-set for audio messages;

3. A set of six "response evaluation" lights in two rows of three, the top row labelled ROLL OK, PITCH OK, POWER OK against a green background, and the bottom row labelled ROLL ERROR, PITCH ERROR, POWER ERROR against a red background.

The response mechanisms that the student may use are:

1. A simulated stick and throttle, with a "trigger" switch on the stick.

2. A row of 5 response buttons, labelled A, B, C, D, and R.

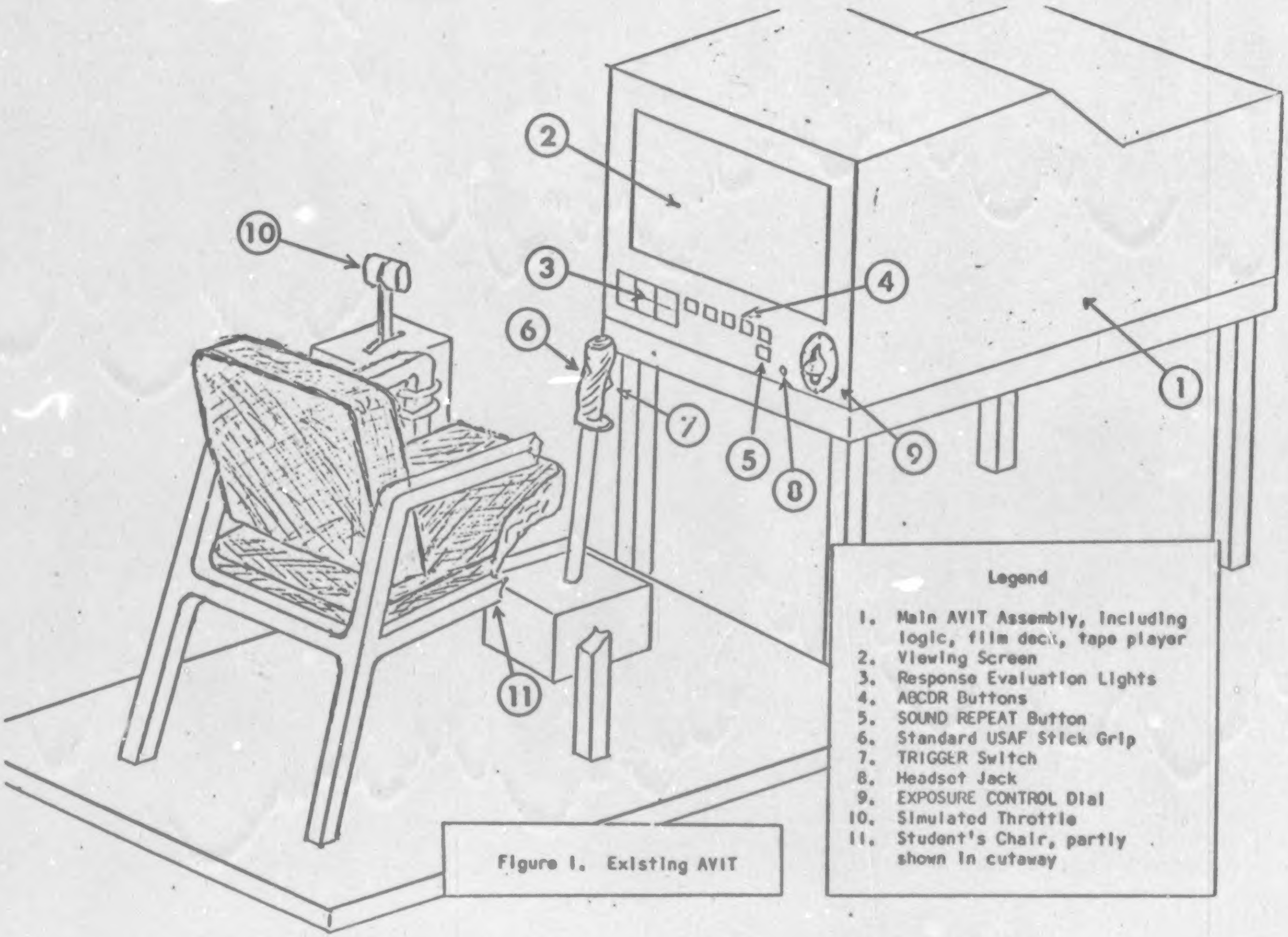
In addition to the above the student has available a SOUND REPEAT button, which allows him to repeat an audio message, and an EXPOSURE CONTROL dial, the use of which will be described later.

### Trainer Mode

The AVIT operates in a number of different modes, which are selected automatically by the program material. The basic TRAINER mode will be described first.

Early in an AVIT program a typical program segment (Figure 2) might be as follows: on frame 20 of the program, following some introductory material, the student might see on the screen a photo of the instrument panel with all the instruments showing the readings that are correct for a particular flight condition, as shown in Figure 3. The accompanying audio message (A-10) reviews the readings and instructs the student to press his trigger switch to advance the first problem frame, frame 21.

On frame 21, all instrument readings might be normal except for a small increase in altitude. There will be no sound message with frame 21, but the student will have been instructed previously that he is to make the appropriate control movements to return to his required flight condition. He moves the controls to the position he desires and presses his trigger switch to "register" his response.



Legend

1. Main AVIT Assembly, including logic, film deck, tape player
2. Viewing Screen
3. Response Evaluation Lights
4. ABCDR Buttons
5. SOUND REPEAT Button
6. Standard USAF Stick Grip
7. TRIGGER Switch
8. Headset Jack
9. EXPOSURE CONTROL Dial
10. Simulated Throttle
11. Student's Chair, partly shown in cutaway

Figure I. Existing AVIT

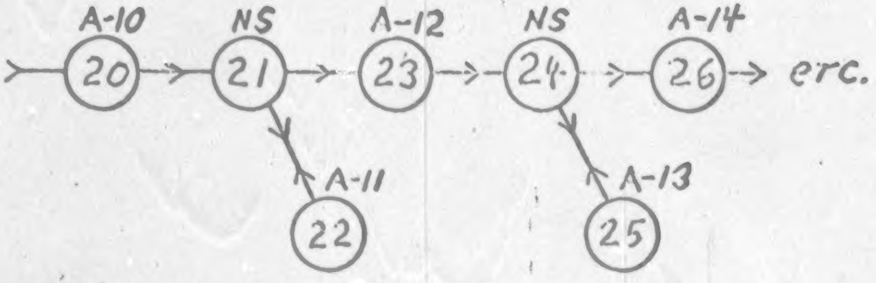


Figure 2. Simple AVIT Sequence With Confirmation Frames.

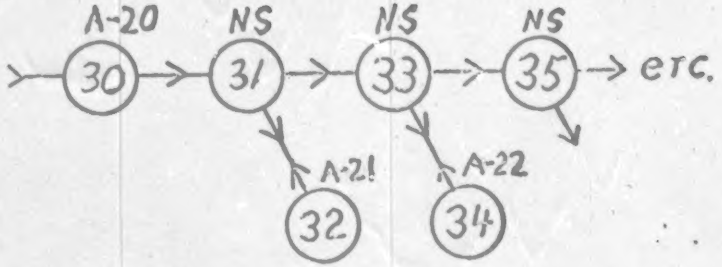


Figure 4. Simple AVIT Sequence, Confirmation Frames Omitted.

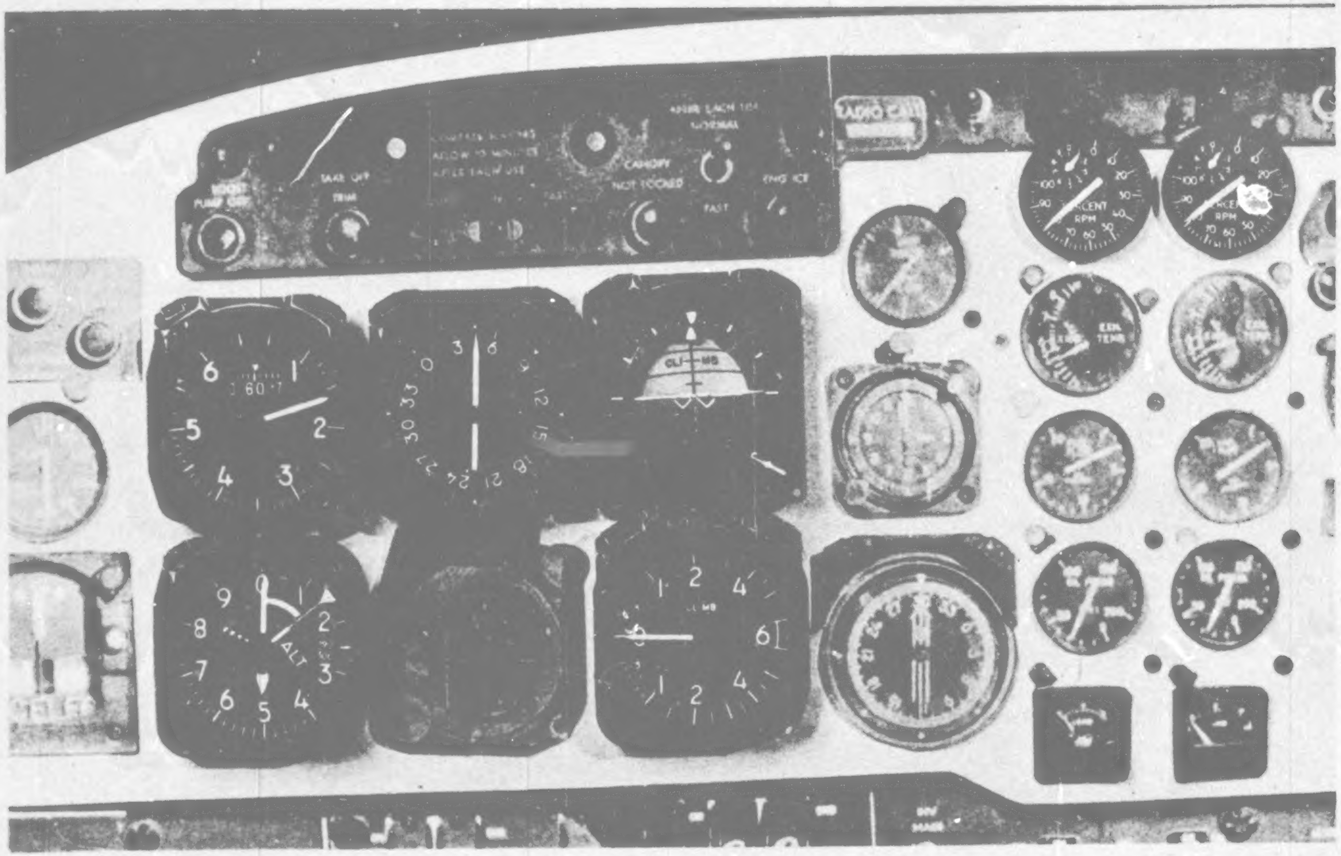


Figure 3. Portion of T-37 Instrument Panel Shown on AVIT Screen.

If he has responded incorrectly the AVIT will move automatically to frame 22. The visual material on frame 22 will be the same as on frame 21, but there will be an audio message (A-11) which will call attention to the specific instrument readings requiring corrective action. In addition, the appropriate response evaluation lights will come on. The audio message might be:

> "Here your attitude, airspeed and heading are all right, but you are 100 feet above your assigned altitude. Check the lights to see where your specific error was and then press the trigger to return to try the problem again".

When the student presses the trigger the AVIT returns to frame 21, and the response evaluation lights go out, of course.

When the student has made the right response the AVIT will move to frame 23. The visual presentation on frame 23 will be the normal set of readings as on frame 20, and the sound message (A-12) will specifically confirm the correctness of the response. For example, A-12 might be:

"Very good. The only problem was a 100 foot error on the altimeter. Forward stick was needed to begin a return to 15,000 feet. For this small decrease in altitude, no power change would be necessary. Very well, press the trigger switch for the next problem."

When the student pressed the trigger, the AVIT would move forward to frame 23, and so on.

Later in the program, the confirmatory frame would be omitted, and the student making the correct response would move directly to the next problem frame. The green lights would come on briefly to confirm the correctness of his response, and he would have previously been instructed that he should respond to the new problem directly. Such a program segment is shown in Figure 4.

The program segment structures just discussed are of the simplest kind and the AVIT is capable of handling much more complex structures. Figure 5 shows a 5-question "pretest" structure, arranged so that the student who passes the pretest with a perfect score will automatically skip a particular instructional sequence. Frame 40 is the introductory frame for the pretest, Frames 41, 42 and 43 are a "warm up" problem on which an error will be "forgiven", and the audio message on frame 43 (A-27) would warn the student that from now on it was "for real" and ask him to press his trigger to begin the test.

In Figure 5, the problem frames as such are frames 44, 46, 48 and 50 and 52. Any error leads the student to frame 55, where the instruction on the particular topic begins. The student who gets all 5 problems right comes to frame 54. The possible excursion from frame 54 to 55 represents the fact that we might offer the student who reaches frame 54 the option

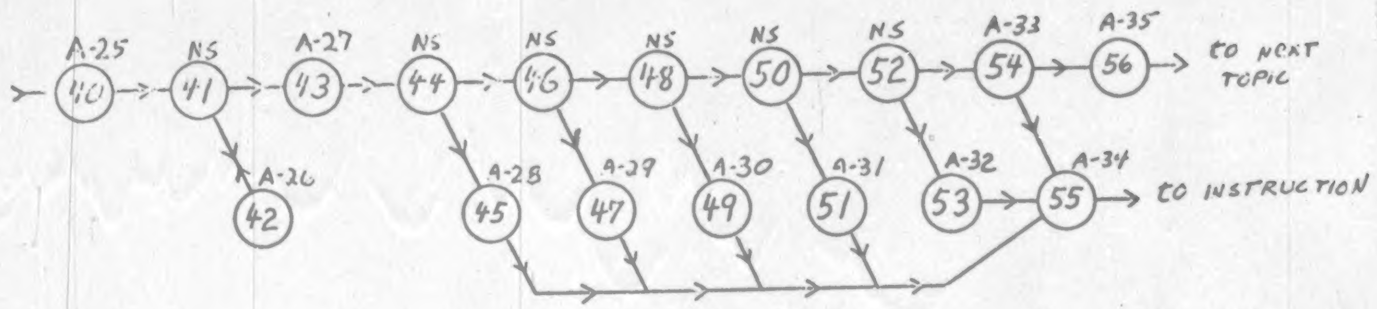


Figure 5. Pre-test or "Wash-Ahead" AVIT Program Structure.

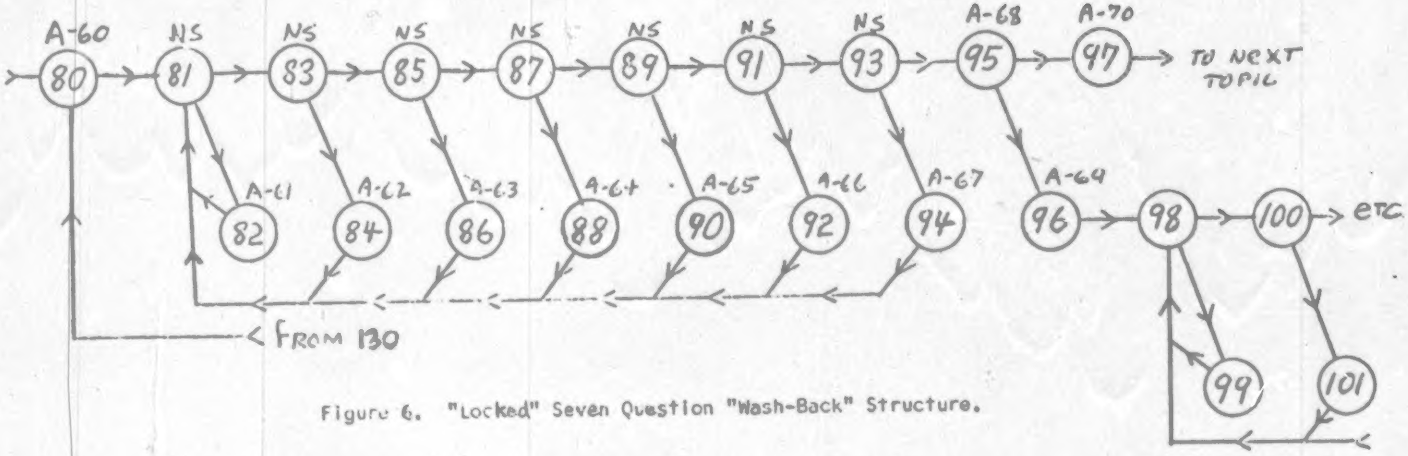


Figure 6. "Locked" Seven Question "Wash-Back" Structure.

of going through the instruction on the particular maneuver if he desires to do so, even though he has passed the pretest. (How the student indicates his choice on frame 54 will be discussed under DIDACTIC mode later.)

Both students and instructor-pilots have been enthusiastic about the program structure shown in Figure 6, used in connection with the EXPOSURE CONTROL mentioned previously. Basically, the structure is a 7 problem test sequence where any error returns the student to the start of the sequence. On the introductory frame (80), however, the student's attention is called to the EXPOSURE CONTROL switch, which has the following settings: SELF-PACED, 11 secs, 8 secs, 5 secs, 3.5 secs, and 2.5 secs. The discussion so far has assumed that this control was set on SELF-paced, and that, therefore, the problem remained on the screen until the student pressed the trigger switch to register his response. On the timed settings the trigger switch is automatically pressed (in effect) at the end of the time set. If the student has not moved the controls to the correct position at the expiration of the set time, he will score an error, of course. If he is correct, he moves on to the next problem. (He can, of course, register his answer in the normal way, by pressing his trigger switch, even with the EXPOSURE CONTROL timer on, if he does so before the time expires.)

The EXPOSURE CONTROL timer works only on problem frames (such as 81, 83, 93 in Figure 6.) It would not work on the "wrong answer" frame such as 82, so the student who is working with a low setting, such as 3.5 secs. gets a "breather" if he makes an error, at least.

The student who gets all 7 problems correct emerges at frame 95, where he is congratulated by the audio (A-68) and offered the opportunity to begin another similar sequence, perhaps at a lower time setting. In one AVIT program there are three such seven-question sequences in a row, and if the student wants more practice after completing all three, he can elect to go back to the first set of exercises, and so on.

Some appreciation of the flexibility of the audio system used in the AVIT may be obtained from the last two patterns discussed, particularly that shown in Figure 6. Visual stimulus presentation devices that permit flexible presentation have been available for some time, but audio and audio-visual devices have generally been locked into a fixed sequence. In contrast consider how the audio apparatus in the AVIT must function to permit the pattern shown in Figure 6. When frame 81 appears on the screen, the audio device (a tape player) has the tape so positioned as to be ready to play audio message A-61. If the student gives the right answer, the AVIT logic switches the tape player to FAST FORWARD and runs to the beginning of audio message A-62, but does not play it. If an error is made (on frame 81) the tape player simply switches to PLAY and plays A-61, stopping automatically at the end of the message. When the student, on frame 82, presses the trigger switch to return to frame 82, the tape player must switch to REWIND, rewind message A-61 and be ready to play it again. If the student makes an error on frame 93 and so goes to frame 94, the tape recorder will play audio message A-67, of course. When the student presses the trigger to return to frame 81, however, the tape player must now rewind 6 messages, and stop in a position ready to play A-61 again.

## DIDACTIC MODE

Mention was made of the five lettered buttons A, B, C, D, and R. The AVIT is a further development or modification of the AutoTutor Mark 4, which is a branching teaching machine. The student using a Mark 4 responds to multiple choice questions by pressing buttons and the Mark 4 "branches" the student to appropriate visual material on the basis of the student's response. A similar capability is built into the AVIT, and allows it to operate in the DIDACTIC mode. The DIDACTIC mode has two major purposes:

1. First, for instructional sequences where a multiple choice question is appropriate. For example, the visual presentation might be the altimeter alone, and the student would be required to select the altitude shown from 4 choices appearing as numbers on the screen, with a button designation beside each. The student choosing the right answer would advance to the next instruction frame and question. For the student who makes an error, two options are available. In the DIDACTIC mode, the AVIT can operate in a full branching sub-mode, so that each button leads to a different frame, or in a "right-wrong" branching mode in which the right answer leads to one particular frame, all wrong answers to a single second frame. The choice depends on whether a single correctional frame is appropriate for all the errors, or whether it is desired to supply specific correctional material for each error. [The reader will recognize that the sequences shown for the TRAINER mode all use "right-wrong" branching. In fact, the full branching option is available in the TRAINER mode also, but we found no practical use for it in the TRAINER mode and would not propose to include this option in an AVIT designed for helicopter instrument training.] In any event, the inclusion of the DIDACTIC mode of operation allows "conventional" branching programmed instruction to be freely intermixed with instruction in the TRAINER mode.

2. The second use made of the DIDACTIC mode is where the student is offered options as to how he wishes to proceed through the program. Such choice points were shown in the program segments shown in Figures 5 and 6, where the student may elect frame 54 to go through an instructional sequence he is "entitled" to skip by having passed the pre-test for the maneuver, and in the segment shown in Figure 6, frame 95, where the student may elect to take another test sequence or to go on to the next maneuver.

## OTHER MODES

Strictly speaking, the AVIT has several other modes of operation which will be mentioned briefly. They and their uses are largely self-explanatory.

MANDATORY FWD mode (MF) no option, used for procedural frames.

Excursion is initiated by pressing the trigger switch. Frames 40, 43, 47, 49, 51 and 53 in Figure 5 are examples.

MANDATORY RVS mode (MR) No option, used for procedural frames.

Excursion is initiated by pressing the trigger switch or the R button. Frames 82, 84, 86, 88, 90, 92 and 94 in Figure 6 are examples.

AUTO ADVANCE mode (AA) In this mode, the AVIT advances automatically to the next frame (in the logical, not necessarily the numerical sequence) as soon as the sound message for the frame is finished. This mode has two uses. First, it allows an AVIT program to contain segments of conventional audio-visual material similar to that used with synchronized sound-slide devices, and this frequently a useful programming resource. The second use of the AUTOMATIC ADVANCE mode is for excursions that are too long to be covered in a single jump. The longest single excursion possible in the AVIT for the visual material is 64 frames forward or backward, and 31 messages forward or 29 backwards on the audio. If a longer excursion is required, the programmer simply includes an AUTOMATIC ADVANCE frame at the appropriate point, and automatically begins a new excursion from that point. With this resource excursions of any reasonable length become possible.

It should be re-emphasized that the selection of the desired mode on a particular frame is entirely automatic, requiring no attention from the student or from a supervising instructor. The only control the student or instructor has occasion to use on the AVIT (except for the response devices, of course) is the EXPOSURE CONTROL switch.

# APPENDIX H

## A Recommended Design for Experimental Studies Using ASUPT

R. G. Demaree

Brief. Described herein is a design which lends itself to studies of the relationships of piloting performance to conditions of simulation provided by ASUPT. The information yielded by the design and the way in which it works are described for an illustrative study. Applications and extensions of the model, though they remain to be specified, are touched on briefly.

General. In the training of pilots, as well as in performance studies using experienced pilots, the conditions under which piloting tasks are performed in ASUPT will often be of an incremental nature. In performance studies involving highly proficient pilots, however, progressive degradations or reductions in features of simulation may be introduced for the purpose of determining the extent to which performance of piloting tasks depends on such conditions. In either of these cases, the design described in this paper would apply.

Characteristics of the design. The design calls for stepwise increments or decrements in simulation with an equal number of observations of performance at each step. Each step will be spoken of as a condition of simulation. Each condition is either present or absent, but a step-down or step-up arrangement holds, whereby the presence of a particular condition implies that conditions up to that point are present, or conversely, that conditions down to that point are absent.

With the above arrangement of sets of conditions under which piloting performance is observed, an estimate of the multiple linear regression coefficients for predicing a pilot's performance score on a given maneuver under a given set of conditions can be obtained very easily from the difference of his scores under adjacent sets of conditions. Such estimates can be extended to differences among corresponding scores when more than one performance score is obtained for a given maneuver under different sets of conditions of simulation.

When two or more observations of performance are obtained for a single pilot under each set of conditions, the estimated multiple linear regression coefficients are given by the mean of the difference scores under adjacent sets of conditions. This also applies to studies in which performances are observed under each set of conditions for two or more pilots. The mean performance is computed for each set of conditions. Each estimated regression-coefficient is then equal to the difference in mean performance for a pair of adjacent sets of conditions. It might be noted here, even though the example given later will make this much clearer, that the step-up (or step-down , if one wishes) arrangement of conditions implies that if there are p conditions there will be $p+1$ sets of conditions. Further, since the regression coefficients are based on the differences between two scores the same results are obtained for raw scores as for scores expressed in mean-deviation form. Specifically, $(Y_1 - Y_2) = [(Y_1 - \bar{Y}) - (Y_2 - \bar{Y})]$.

An example of how the design works. In the example which follows, there is a step-up arrangement for four conditions of simulation. The five sets of conditions under which performance of a given piloting task is observed on a single pilot can be represented by a matrix, as follows:

$$\text{Set of Conditions}\quad \begin{array}{cc} & \text{Conditions} \\ & \begin{array}{cccc}1 & 2 & 3 & 4\end{array} \\ \begin{array}{c}1\\2\\3\\4\\5\end{array} & \begin{bmatrix}0 & 0 & 0 & 0\\1 & 0 & 0 & 0\\1 & 1 & 0 & 0\\1 & 1 & 1 & 0\\1 & 1 & 1 & 0\end{bmatrix}\end{array} \qquad \begin{array}{c}\underline{Y}_1\\ \begin{bmatrix}Y_{11}\\Y_{21}\\Y_{31}\\Y_{41}\\Y_{51}\end{bmatrix}\end{array} \quad \begin{array}{c}\underline{Y}_2\\ \begin{bmatrix}Y_{12}\\Y_{22}\\Y_{32}\\Y_{42}\\Y_{52}\end{bmatrix}\end{array}$$

$Y_{i1}$ is the performance score under the $i^{th}$ set of conditions for Trial 1 by a single pilot. $(i = 1,2,3,4,5)$.

$Y_{i2}$ is similarly defind for Trial 2.

X is the 5x4 matrix which denotes the conditions under which performances are observed.

$$\begin{array}{c}\hat{\underline{b}}_1\\ \begin{bmatrix}\hat{b}_{11}\\ \hat{b}_{21}\\ \hat{b}_{31}\\ \hat{b}_{41}\end{bmatrix}\end{array} = \begin{bmatrix}(Y_{21} - Y_{11})\\(Y_{31} - Y_{21})\\(Y_{41} - Y_{31})\\(Y_{51} - Y_{41})\end{bmatrix} ; \quad \begin{array}{c}\hat{\underline{b}}_2\\ \begin{bmatrix}b_{12}\\b_{22}\\b_{32}\\b_{42}\end{bmatrix}\end{array} = \begin{bmatrix}(Y_{22} - Y_{12})\\(Y_{32} - Y_{22})\\(Y_{42} - Y_{32})\\(Y_{52} - Y_{42})\end{bmatrix}$$

$\hat{\underline{b}}_1$ is the 4x1 vector of estimated multiple linear regression coefficients, based on Trial 1.

$\hat{\underline{b}}_2$ is similarly defined for Trial 2

$\hat{\underline{b}}$ is the 4x1 vector of estimated regression coefficients, based on Trials 1 and 2.

$$\begin{array}{c}\hat{\underline{b}}\\ \begin{bmatrix}\hat{b}_1\\ \hat{b}_2\\ \hat{b}_3\\ \hat{b}_4\end{bmatrix}\end{array} = 1/2\ (\underline{b}_1 + \underline{b}_2) - 1/2 \begin{bmatrix}(Y_{21} + Y_{22}) - (Y_{11} + Y_{12})\\(Y_{31} + Y_{32}) - (Y_{21} + Y_{22})\\(Y_{41} + Y_{42}) - (Y_{31} + Y_{32})\\(Y_{51} + Y_{52}) - (Y_{41} + Y_{42})\end{bmatrix} = \begin{bmatrix}(Y_{2.} - Y_{1.})\\(Y_{3.} - Y_{2.})\\(Y_{4.} - Y_{3.})\\(Y_{5.} - Y_{4.})\end{bmatrix}$$

where $Y_{i.}$ is the mean of the performance scores under the $i^{th}$ set of conditions.

The least-squares prediction equation takes the form:

$\hat{\underline{Y}} = x\,\underline{b}$ , where

$\hat{\underline{Y}} = \begin{bmatrix} \hat{\underline{Y}}_1 \\ \cdots \\ \hat{\underline{Y}}_2 \end{bmatrix}$ , $\hat{\underline{Y}}$ is the 10x1 vector of predicted performance scores in mean-deviation form;

x is the 10x4 matrix of predictor variables in mean-deviation form, representing the sets of conditions under which the observed performance scores were obtained; and, $\hat{\underline{b}}$ is the 4x1 vector of regression coefficients. The ratio of the variance of the predicted performance scores to the variance of the observed performance scores is equal to the squared coefficient of multiple correlation.

Thus, $R^2_{Y.1234} = \dfrac{\sigma^2_{\hat{Y}}}{\sigma^2_{\underline{Y}}}$, where $\sigma^2_{\hat{y}} = \frac{1}{N}\hat{\underline{Y}}'\hat{\underline{Y}}$ ; $\sigma^2_{\underline{Y}} = \frac{1}{N}\underline{Y}'\underline{Y}$ , and N is the number of observations (10 in the present case).

Due to the fact that the matrix of independent or predictor variables forms what is called an equally-spaced simplex, the prediction equation is simply

$\hat{Y}_{ij} = Y_{i.}$ ,

where

$\hat{Y}_{ij}$ is the predicted performance score under the ith set of conditions on the $j^{th}$ trial, and

$Y_{i.}$ is the mean performance score under the $i^{th}$ set of conditions.

From the above it can perhaps be seen that if a pilot's performance under each set of conditions were identical for both trials, $Y_{i.}$ would be equal to $Y_{ij}$ and, as a consequence, $R^2_{\underline{Y}.1234}$ would be equal to 1.00.

The example, described above, could be applied just as readily to two pilots for whom one performance score was obtained under each set of conditions, as in the present case of one pilot for whom two performance scores were obtained under each set of conditions. The extension to more than four conditions of simulation is straightforward, as long as the same number of observations of performance is obtained for each of the p+1 sets of conditions. When this is not the case, the multiple linear prediction equation is not as simple as in the example given. Specifically, a predicted score under the $i$th set of conditions would then be based on observed performances under the $(i-1)$, $i$, and $(i+1)$ sets of conditions, except for $i=1$, in which case only $i$ and $(i+1)$ apply and $i=p+1$, in which case only $(i-1)$ and $i$ apply.

*Further applications of the simplex design.* An interesting, and perhaps highly useful, application of the simplex design would be one in which the conditions of simulation are permitted to vary so that equal increments in performance are obtained. The regression coefficients would then be equal in value and the question of interest would be to ascertain the conditions of simulation e.g., the $k$ values which range from 0 to 1 for components of motion simulation, required for attaining equal increments (or decrements) in observed performances. The usual model for multiple linear regression would apply directly, except that the increments in performance would be required to be equal and the conditions of simulation would become the dependent variables.

Finally, it is worthy of note that the simplex design as described in this paper is a fully-crossed design inasmuch as each pilot's performance is observed under all sets of conditions, trials, and tasks. The resulting data for a given performance score (dependent variable) lend themselves to an analysis of variance which leads to estimated components of variance. Computer programs are already available[2] for such analyses or can be readily developed.

---

[2] Cornelius, E. T., Woodward, J. A., and Demaree, R. G., *CRONB: A Fortran IV program to compute variance components for various experimental designs.* Fort Worth, Tex.: Institute of Behavioral Research, Texas Christian University, March, 1972.

## APPENDIX I

## LIST OF TRAINING PROBLEM PANEL MEMBERS

Dr. Paul W. Caro
Human Resources Research Office (Division 6)
P. O. Box 428
Ft. Rucker, Ala. 36360

Prof. Ralph E. Flexman
Director, Institute of Aviation
University of Illinois
Willard Airport
Savoy, Ill 61874

Dr. Robert C. Houston, Director
Training Equipment/Program Development
American Airlines Flight Academy
Greater Southwest Airport
Fort Worth, Tex. 71625

Mr. Dave Killian
Training Equipment/Program Development
American Airlines Flight Academy
Greater Southwest Airport
Fort Worth, Tex. 71625

Dr. George E. Long
McDonnell Douglas Astronautics Company - East
St. Louis, Missouri 63166

Dr. Don E. Meyer
Headquarters Air Training Command
Randolph Air Force Base, Tex. 78148

Mr. Robert J. Ontiveros
Department of Transportation
Federal Aviation Administration
National Aviation Facilities Experimental Center
Atlantic City, New Jersey 08405

Dr. Malcolm L. Ritchie
Ritchie, Inc.
630 Brubaker Drive
Dayton, Ohio 45429

Mr. Benjamin Schohan
Missile Systems Division
Rockwell International
4300 E. Fifth Avenue
Columbus, Ohio 43081

Dr. Edward A. Stark
Singer Company
Simulation Products Division
Binghamton, New York 13905

Mr. Donald Vreuls, President
Canyon Research Group, Inc.
Suite 123
32107 Lindero Canyon Rd.
Westlake Village, Calif. 91361